A

COURSE OF LECTURES

ON

CHEMICAL SCIENCE,

AS

DELIVERED

AT

THE SURREY INSTITUTION.

By GOLDSWORTHY GURNEY.

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PREFACE.

When I engaged, in the autumn of 1822, to deliver a series of Elementary Lectures on Chemistry, at the Surrey Institution, I had no thoughts of publishing them afterwards, because at that time I had nothing new or sufficiently valuable to offer to the scientific world on this subject. In the course, however, of the studies and investigations which I thought it my duty to institute, in order to render the Lectures as instructive as possible to my audience, I found myself led, as it were, imperceptibly into inquiries and experiments, which seemed to me to open new and important views into many branches of the science. Several inquiries I was compelled to abandon

at the very threshold, on account of the distance they threatened to lead me from the elementary course of knowledge that I had engaged to expound; others I was tempted to prosecute, as far as circumstances would permit; and it remains for the scientific world to determine whether the matter which I have now published is worth their acceptance. In the mean time I may be allowed to state, that my inducement to publish these Lectures has been partly my own belief, but chiefly the opinions of several valuable and scientific friends, that the investigations I have made are interesting and important; and, let me add, the consequent feeling on my part, that I ought not carelessly to abandon any claims that I may possess to the credit of having, at least, contributed my earnest endeavours to further the true interests of science.

Any imperfections that may be observable in the arrangement of these Lectures, or faults in the language in which they

appear, will, I hope, be candidly attributed to the unavoidable engagements attendant on an arduous profession preventing me from applying myself to the niceties of literary composition; and also in some degree to my inexperience in the practice of correcting the errors of the press, which, in a work of this nature, can be adequately done by the writer of it alone.

7, Argyll Street, July 2, 1823.

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LECTURES

ON

CHEMISTRY.

LECTURE I.

INTRODUCTORY.

As it is the avowed object of this establishment to blend rational amusement with instruction, particularly in the Lectures it causes to be delivered in this theatre, I am tempted to open my Introductory Discourse by laying before you a brief historical sketch of those remarkable pursuits which, under the much-ridiculed title of *Alchemy*, so long occupied the attention of speculatists in England, and even in all Europe, for ages before Chemistry can be said to have existed at all as a regular science. I conceive that, in prosecuting this plan, I shall not be considered as improperly departing from my immediate subject: because, however these "searchers after a vain thing" may have been open to ridicule, on account of the express *object* of their

pursuit (which would have been highly mischievous, even had it been attainable), yet it is not to be denied, that the researches in question have at length led to the construction of a regular science, which is the most important of all others, because it is of all others the most extensively and permanently available for the purposes of actual life. And I enter into this sketch the rather, because I fear that, as this first Lecture does not admit of being illustrated by experiments, it might otherwise not be so generally interesting as I hope to render those which are to follow.

It has not unfrequently happened, that the highest achievements of human wisdom have had their root in the lowest absurdities of human weakness; and that the severest truth has sprung from the most ludicrous and exaggerated fictions of mingled folly and fanaticism. This fact is strikingly, and I cannot but think most impressively exemplified, in the sciences of astronomy and chemistry, as they exist in the present day. The first of these unquestionably arose out of the insane passion, which was once so prevalent all over Europe, for casting nativities, and horoscopes for questioning the stars of heaven, in order to ascertain the past or future destinies of the inhabitants of the earth; and there can be little doubt, as I have before hinted, that the idle, im-

pious, and ridiculous search after a menstruum which shall change all other metals into gold, and an elixir which shall prolong human life interminably, first pointed out the direction, and afterwards cleared the path, which has at length conducted us to the admirable science of modern chemistry.

Alchemy, like all the other abstruse sciences, must be referred to an Egyptian origin. We can trace it thus far back, but there we are compelled to leave it, enveloped in that mist of obscurity which surrounds it, in common with all other Egyptian learning.

Alonzo of Castile (surnamed *the Wise* by his admirers, and *the Astrologer* by those who were disposed to ridicule his pretensions), was the great modern patron as well as preacher of alchemy and astrology; and he speaks of an Egyptian as having been his instructor in both these arts. It may be stated here, that the transmutation of metals was not only regarded as *possible*, but was *firmly believed to have been performed*, in many instances, and by various practisers of the art. In fact, Alonzo of Castile himself, in the *Book of the Treasure*, as it is called, boasts of actually possessing the secret, and of having used it to increase his wealth. He says, "in secrecy I was instructed in this inestimable treasure, and therewith did I increase my wealth." A copy of this

curious book is still extant in the royal library at Madrid. It is remarkable, too, or rather, perhaps, I should say it is *not* remarkable, that letters are also extant, in which the possessor of this "inestimable treasure" solicits alms; and it is known that at one time he had pawned his crown jewels to raise supplies of money.

During the period at which the study of alchemy was most prevalent, it was professedly regarded as a high, and almost sacred art, fit only to be known and practised by the pure, the learned, and the wise. It was studied by the clergy more than by almost any other set of men; and such of the sacred edifices as still remain to us belonging to that period, exhibit numerous symbols and hieroglyphics of the art. In this country, in particular, many of the prelates of Westminster are known to have been adepts; and the abbey itself remains to this day not without allegorical symbols connected with this practice. And Elias Ashmole, who wrote on this subject about the middle of the seventeenth century, relates that in his time St. Margaret's church contained a richly painted window, in which the whole process of the work was typified. He gives a very curious and detailed account of this window, which was shortly afterwards destroyed by the Puritans. The abbey church of Bath also still retains symbols which may fairly be

considered as relating to alchemy; and the rather because William Bird, the last prior of that abbey while it remained subservient to the unreformed faith, was an adept of considerable note.

In confirmation of the fact that alchemy was greatly encouraged by the Catholic clergy in other parts of Europe also, it may be stated, that many of the religious edifices of France still exhibit symbols of a like nature with those described by Ashmole as having existed in Westminster Abbey. In the cloister walk belonging to the cemetery of the Innocents at Paris, there till lately existed the remains of certain hieroglyphical paintings, unquestionably relating to alchemy; and the whole ornamental part of the west front of Notre Dame, in the same city, consists of hieroglyphical statues, medallions, &c., which are said to indicate the methods to be used in order to complete the great work. The first name which is usually connected with alchemy is that of *Hermes Trismegistus;* but it should, perhaps, as far as regards any actual knowledge that we possess respecting the owner of it, be considered as a name, and nothing else. He is supposed to have lived more than four thousand years ago, and the works which are attributed to him may safely be regarded as altogether spurious, and of a comparatively modern date.

The first name to whose possessor we are really

indebted is *Geber* ; who is said to have flourished somewhere about the seventh century of the Christian era. Supposing the work which bears this philosopher's name to be genuine (of which there is room, however, for considerable doubt), Geber must be regarded as a person who possessed vast knowledge as well as genius, taking into consideration the times in which he lived. The work which bears his name was published at Strasburgh, in 1520.

In the year 1130 an alchymist, named *Artephius*, published several tracts on the subject of his researches ; and, if we are to credit our own Roger Bacon, there can be little doubt that this Artephius had made no slight progress towards the discovery of *one*, at least, of the grand secrets, since this celebrated philosopher relates that he died at the somewhat advanced age of ten hundred and twenty-five years! Next in rotation is to be placed *Roger Bacon* himself. He was an Englishman, and was born at Ilchester, in Somersetshire. In the early part of his life he went to France, and became a Franciscan friar ; but in 1220 we find him returned from Paris, and engaged in the valuable and enlightened, but at the same time dangerous attempt, to expose the ignorance of the learned of that day, and overthrow the dogmas of the schools. Roger Bacon's celebrated *Opus Majus* may be regarded as the work

of a high intellect, swayed and moulded by a vast fund of uncertain knowledge; and it has been remarked by Mr. Hallam, in his History of the Middle Ages, that "whoever reads the sixth part of the *Opus Majus*, upon experimental science, must be struck by it as the prototype in spirit of the *Novum Organum*." In fact, it is not improbable that the great father of modern experimental philosophy (I mean the *Chancellor Bacon*) had read and studied the work of his namesake and predecessor. *Albert of Cologne* was a cotemporary of Roger Bacon. It was he who invented the celebrated brazen head, which is so usually associated with the name of Bacon. *Albertus Magnus* added to his almost universal acquirements, that of great skill in the higher departments of alchemy.

Raymond Lully, *Nicholas Flammel*, and *Sir Kenelm Digby* are the other most celebrated names connected with alchemy in the sixteenth and seventeenth centuries, after which it nearly ceased to be studied as a regular art. In later times, however, even up to our own day, we have had confirmed believers in the truth and practicability of its doctrines, as I shall shew in the course of a few anecdotes relating to this singular and interesting subject. *Raymond Lully*, who first came over to England in the reign of Edward the First, was firmly believed to have been in the habit of

making gold for the use of that monarch. He was introduced to Edward by *Cremer*, the abbot of Westminster; and certain it is that, by some means or other, he made it appear that he from time to time furnished the Royal Mint with gold to the amount of *six millions sterling*. The Abbot Cremer declares also (on the most solemn occasion, namely, in his last will and testament), that Lully at length refused to make any more money for the King, because he did not employ it solely in fit and pious uses, but applied part of it to making war upon the Scots instead of the infidels! In consequence of this refusal Lully was actually imprisoned in the Tower, and only escaped by stratagem. That the belief in the transmutation of inferior metals into gold was at this time prevalent, even among the highest and best informed classes of society throughout Europe, cannot for a moment be doubted; and in England the question seemed to be, not whether it *could* be effected, but whether it *was lawful* to effect it. And in the reign of Henry the Sixth a law was actually passed decreeing such transmutation (or *multiplication*, as it was sometimes called,) to be felony. But the most remarkable anecdote extant, concerning the belief in the power of alchemy, is related by so grave an authority, and in so curious and circumstantial a manner, that I cannot refrain from repeating it to you; without, however, attempting

to explain either the nature of the deception, or the manner in which the relater may be supposed to have admitted the belief to fix itself upon him: for it appears that, until this time, he had been singularly sceptical on the subject, and had actually written a treatise discountenancing the belief. The story is thus related of himself, by the Dutch philosopher *Helvetius* :

" The 27th day of December 1666, in the afternoon, came a stranger to my house at the Hague, in a plebeian habit, of honest gravity and serious authority, of a mean stature and a little long face, black hair not at all curled, a beardless chin, and about forty-four years (as I guess), and born in North Holland. After salutation, he beseeched me with great reverence to pardon his rude accesses, for he was a lover of the pyrotechnian art, and having read my treatise against the sympathetic powder of Sir Kenelm Digby, and observed my doubt about the philosophic mystery, induced him to ask me if I really was a disbeliever as to the existence of an universal medicine, which would cure all diseases, unless the principal parts were perished, or the predestinated time of death came. I replied, ' I never met with an adept, or saw such a medicine, though I had fervently prayed for it.' Then I said, ' surely you are a learned physician ?' ' No,' said he : ' I am a brass-founder, and a lover of chemistry.' He

then took from his bosom-pouch a neat ivory box, and out of it three ponderous lumps of stone, each about the bigness of a walnut. I greedily saw and handled, for a quarter of an hour, this most noble substance, the value of which might be somewhere about twenty tons of gold; and having drawn from the owner many rare secrets of its admirable effects, I returned him this treasure of treasures with a most sorrowful mind, humbly beseeching him to bestow a fragment of it upon me in perpetual memory of him, though but the size of a coriander seed.

" 'No, no,' said he, 'that is not lawful, though thou wouldest give as many golden ducats as would fill this room, for it would have particular consequences; and if fire could be burned of fire, I would at this instant rather cast it all into the fiercest flames.' He then asked if I had a private chamber whose prospect was from the public street; so I presently conducted him to my best furnished room backwards, which he entered," says Helvetius (in the true spirit of Dutch cleanliness) " without wiping his shoes, which were full of snow and dirt. I now expected he would bestow some great secret upon me, but in vain. He asked for a piece of gold, and opening his doublet, showed me five pieces of that precious metal which he wore upon a green riband, and which very much excelled mine in flexibility and

colour, each being the size of a small trencher. I now earnestly again craved a crumb of the stone; and at last, out of his philosophical commiseration, he gave me a morsel as large as a rape seed; but I said, 'this scanty portion will scarcely transmute four grains of lead. Then said he, 'deliver it me back:' which I did, in hopes of a greater parcel; but he, cutting off half with his nail, said, 'even this is sufficient for thee.' 'Sir,' said I, with a dejected countenance, 'what means this?' and he said, 'even that will transmute half an ounce of lead.' So I gave him great thanks, and said I would try it, and reveal it to no one. He then took his leave, and said he would call again next morning at nine. I then confessed, that while the mass of his medicine was in my hand the day before, I had secretly scraped off a bit with my nail, which I projected on lead; but it caused no transmutation, for the whole flew away in fumes. 'Friend,' said he, 'thou art more dexterous in committing theft than in applying medicine; hadst thou wrapt up thy stolen prize in yellow wax, it would have penetrated and transmutated the lead into gold.' I then asked if the philosophic work cost much or required long time, for philosophers say that nine or ten months are required for it. He answered, 'their writings are only to be understood by the adepts, without whom no student can prepare this magistery.

Fling not away, therefore, thy money and goods in hunting out this art, for thou shalt never find it.' To which I replied, 'as thy master showed thee, so mayest thou perchance discover something thereof to me, who know the rudiments, and therefore it may be easier to add to a foundation than begin anew.' 'In this art,' said he, 'it is quite otherwise; for unless thou knowest the thing from head to heel, thou canst not break open the glass seal of Hermes. But enough: to-morrow, at the ninth hour, I will show thee the manner of projection.' But Elias never came again; so my wife, who was curious in the art whereof the worthy man had discoursed, teased me to make the experiment with the little spark of bounty the artist had left me; so I melted half an ounce of lead, upon which my wife put in the said medicine; it hissed, and bubbled, and in a quarter of an hour the mass of lead was transmuted into fine gold, at which we were exceedingly amazed. I took it to the goldsmith, who judged it most excellent, and willingly offered fifty florins for each ounce."

Such is the celebrated history of Elias the artist, and Dr. Helvetius.

I shall only refer to one other believer in the mysteries of this art, who lived in our own times and country. The following facts are collected from persons still living, who were acquainted

with him. *Peter Woulfe* occupied chambers in Barnard's Inn when in London, but usually resided in Paris during the summer. His rooms were extensive, but so filled with apparatus, that it was difficult to reach his fire-side. A gentleman states, that he once put down his hat in Woulfe's rooms, and could never find it again, such was the confusion of boxes, packages, &c. that lay about the chamber. His breakfast hour was four in the morning: a few of his select friends were occasionally invited to this repast; to which they gained entrance by a secret signal —knocking a certain number of times at the inner door of his apartment.

He had a singular and heroic remedy for illness. When he felt himself seriously indisposed, he used to take a place in the Edinburgh mail, and having reached that city, used immediately to come back by the returning coach. A cold taken in one of these excursions terminated in his death, in the year 1805. He is the author of several papers in the Philosophical Transactions, and the inventor of some ingenious chemical apparatus, which still bear his name. I now finally take leave of these singular visionaries by mentioning, that I have thought it more expedient to lay before you this slight notice respecting them, than to enter into the regular history of chemistry as a science. To have done the latter, with

any thing like a beneficial effect, would have demanded much more time than the nature of my undertaking would permit; and all the historical notices that are necessary to be given in an avowedly elementary course of instruction, will come more appropriately and effectively when I have occasion to speak of the different parts of my subject to which those notices apply.

My hearers may have attended, or not, to the foregoing sketch, which was meant to have little direct reference to the subject before us, and was offered chiefly with a view to their amusement. But I now venture to claim the honour of their serious attention to what follows,—considering, as I do, that it is of the last consequence they should acquire a general notion of the vast importance of the science they are about to become acquainted with: for, however the fact may be, I am bound to regard the majority of my audience in the light of persons at present unacquainted with the subject of our inquiry.

As it is the primary object of these Lectures to teach the elements of chemical science, I consider that the most effectual mode of preparing my audience for the reception of this knowledge, will be an endeavour to impress them with a sense of its beauty and utility, and thus necessarily engender in them that desire to learn, which is the first and most important step towards all acquirement, and

in the abscence of which no acquirement can be made to any permanent or valuable effect. With this view, I shall devote the remainder of the present Lecture to a cursory consideration of the various aspects under which chemistry may be regarded; its various objects, operations, connexions, and effects.

Viewing the term natural philosophy as applicable to that immense mass of knowledge, which the human mind has been enabled to acquire relative to the general laws and operations of nature, we shall regard chemistry as a *branch* of this philosophy; as a distinct portion of this knowledge; infinitely the most important and interesting portion, since it serves to modify, regulate, and direct nearly all the rest; and since, without it, all would be likely to fall back into that confused mass of vain and empty speculation, from which it has but just emerged; or, rather, without which it never could have emerged from that state.

As it is the object of natural philosophy to attend to the connexions and operations which obtain between the various *external* and *sensible* properties of matter, and thence to deduce *some* of its general laws, so it is the more delicate and recondite province of chemical science tofollow the ultimate particles of matter through their most secret changes of state, and wring from them a knowledge of those invariable qualities and habits;

or, so to speak, those affections and dispositions, with which their great Creator has endowed them, and in virtue of which all their operations take place. In fact, the grand distinction between chemical and all other sciences is, that these latter have to do with the *sensible* and *tangible* appearances and qualities of matter, such as present themselves to the mere bodily senses; whereas chemistry addresses itself to the "mind's eye:" communicating chiefly with those *primary*, and, in many instances, *invisible* operations, to which the former are merely secondary, and on which they are in fact dependent. We fling a stone into the air: and observing the curve which it describes in returning to the earth, we thence deduce the laws of gravitation. Here we have to do with *visible* and tangible objects and effects; and have been examining one of the phenomena of general natural philosphy. But when we collect a portion of two *invisible* substances of known qualities, and, combining them together, produce another invisible substance, whose qualities totally differ from those of the substances which produced it, we have performed an operation in chemical science; though in each case we have only been demonstrating the effect of laws belonging to the ultimate particles of matter.

Chemical, as well as every other science, is to be regarded as a collection of facts arranged under

certain heads and classes, in order to the formation of certain general truths, which are supposed to spring out of these facts; or rather on which these facts are dependent. I state this in order to distinguish the *science* of chemistry from the mere *art*. It is the business of the artist merely to apply his experience to the production of certain *effects*, without attending to the *causes* from which those effects may spring But the scientific man attends to effects almost exclusively with a view to detect their causes, in the first instance, in order that, when he has accomplished this, he may be qualified to suggest or lay down such general rules as shall be invariably applicable in future cases, and thus render mathematically certain what was before dependent on mere accidental circumstances: the *science* of chemistry therefore *includes the art*; but the *art does not include the science*.

When I turn to the consideration of the numerous branches of knowledge with which chemistry is connected, and the immense extent and variety of the subjects of contemplation with which it brings us acquainted, I am equally at a loss efficiently to set forth its value and importance, and duly to admire and extol its power and beauty. It contributes more than any other science, or perhaps than all other sciences united, to unfold to us those laws by which the universe is governed;

which laws have preserved a sublime and uninterrupted order since they were first impressed on matter by its Creator; and in virtue of which that order can alone be expected to be preserved through future ages. I must not neglect to observe, too, that the study of this science, in giving to the imagination an unbounded field of actual reality in which to exercise its functions, tends to prevent that ever-active power from busying itself among those uncertain, and in many cases dangerous speculations, in which, in the absence of other employment, it is but too apt to engage. At the same time it can hardly fail to strengthen and improve all the other intellectual faculties, by perpetually affording them that healthful exercise, without which they either degenerate into a slothful inactivity, or occasionally break out into a restless and diseased action, the consequences of which are frequently still more to be feared.

In thinking of the different branches of inquiry to which the knowledge of chemistry is applicable, the difficulty lies in fixing on one to which it is not so. Even in examining those heavenly bodies which are exterior to our earth, and even to our system,—if it is the province of the astronomer to explain the laws of their motion, it is for the chemist to explain the laws of that influence which we derive from them.

When we confine ourselves still nearer home,

and attend to the various phenomena which occur within the limits of our own atmosphere, we shall have difficulty in naming *one* on which chemistry cannot throw some light, and to the satisfactory explanation of which it is *not absolutely necessary.* From the clouds that roll in interminable masses above our heads, to the smallest grain of earth that is trodden beneath our feet, all is dependent on some chemical law for its existence under a definite and sensible form; and the chemist is as capable of satisfactorily explaining the former as the latter, and equally interested in doing so: for to him there is food for inquiry and contemplation in the smallest and most insignificant object that can be presented to his senses. In fact, it is the chemist who discovers and demonstrates that, in the eyes of Him who has made all things, all are alike important, being alike the work of His wisdom and power, and the subject of His ever-watchful care—that with Him, *little* and *great* are terms of no meaning, the same laws which produce the one being equally capable of producing the other: in short, that a single drop of water, or an ocean—a single spark of fire, or a mass of destroying lightning, are dependent for their action on the same laws, and are generated by the same identical causes.

Without extending these general observations much farther, I may, before proceeding into detail,

remark that there is not a *single science*, and scarcely a *single art*, which has not already been benefited by the application of chemical knowledge, and which may not be still further benefited by it, to a most important extent; from the highest and most intellectual, those which communicate chiefly with the imagination, down to the lowest and most mechanical, those which address themselves chiefly to our bodily wants and senses. And many of these latter, which are so important to the comfort and well-being of our daily lives, are absolutely dependent on chemistry for their very existence, to any good practical result. The working of metals—the manufacture of domestic utensils—the production of fermented liquors—and, above all, the compounding of medicines—in what state should we be without these? And in what state would these be without the existence and application of chemical knowledge? In my mind it is not too much to say, that without chemistry we should (in these latitudes at least) never have emerged from a condition of comparative barbarism; and I will add, that while chemistry exists as a science, we never can return to that state.

I have hinted at the general distinction between science and art, and the effect of their union. In order to judge of the immense importance of a union of this kind between chemical science and the practical arts of daily life, it is only ne-

cessary to refer to the stupendous effects which have resulted from this union, in the use and application of steam in the present day. The discoveries made by Mr. Watt, in regard to this wonderful power, and the admirable ends to which he has applied these discoveries, are sufficient to immortalize his name, either as an artist or a man of science; how much more so, then, as both united! Mr. Wedgwood's exertions have been scarcely less distinguished in a different line. By a similar union of science and art, he has raised the English manufacture of porcelain, &c. to a level with that of her continental rivals; and has thus opened a most extensive and important source, from which our national industry may add to our national wealth and distinction.

With reference to the spirit and manner in which a union of the kind here spoken of should employ itself, I shall quote to you a few sentences from that mass of philosophical wisdom contained in the *Novum Organum* of Lord Bacon. This greatest of philosophers says, "he who would come duly prepared and fitted to the business of interpretation" (he means the interpretation of the laws of nature, as they are deducible from fact and experiment), "must neither be a follower of novelty, custom, nor antiquity; nor indulge himself in a liberty of contradicting; nor servilely follow

authority. He must neither be hasty in affirming, nor loose and sceptical in doubting; but raise up particulars to the place assigned them by their degree of evidence and proof. His hope must encourage him to labour, and not to rest; he must not judge of things by their uncommon nature, their difficulty, or their high character, but by their just weight and use. He must, in his own particular, carry on his view with concealment, and yet have a due regard to posterity. He must prudently observe the first entrance of errors into truths, and of truths into errors, without despising or admiring any thing." (He uses "*admiring*" in the sense of "*wondering at*," which meaning belonged to it till a much later day.) He continues, "he must understand his own talents and abilities, or the advantages of his own nature. He must comply with the nature of others. He must, as with one eye, survey the nature of things, and have the other turned towards human uses. He must distinctly understand the mixed nature of words: which is extremely capable both of prejudicing and assisting. He must lay it down to himself, that the art of discovering will grow up and improve along with the discoveries themselves. He must not be vain either in delivering or concealing the knowledge he has acquired; but ingenuous and prudent, and communicate his inventions without pride or

ill-nature: and this in a strong and lively manner, well defended against the injuries of time, and fit for the propagation of knowledge, without occasioning errors."

Probably there never was before collected together to much practical wisdom in a similar number of words; and it is by a strict adherence to the spirit of these truly enlightened and enlightening aphorisms, that the modern cultivators of science have so wonderfully extended its practical results. I have thus ventured to step somewhat aside from my direct course, in order to have on opportunity of laying before you the above admirable passage: I now return to the general consideration of chemistry, as applied to our daily wants and comforts.

Agriculture, that most important of our practical arts, has to do with a kingdom of regularly organized beings, endowed with a vital principle, the continuance of which in each individual is solely dependent on the reception of certain appropriate food; and this food is capable of fulfilling its end more or less effectually, in proportion as it is presented and received under certain forms and circumstances. It is only necessary to state thus much, in order to shew the importance of being able to apply chemical knowledge to the different processes of agriculture, as a practical art. In order to be acquainted, in the fullest and

most perfect manner, with the relative value and character of different soils and manures, and their precise adaptation to the different kinds of grain, plants, &c. to which their qualities are to be made subservient, chemical knowledge seems indispensable ; and, therefore, if it is not necessary, or perhaps not desirable, that this knowledge should be extended to the active cultivators of the earth, it cannot fail to be most useful and important to those who have the direction of the operations in question.

In many other of the arts connected with the economy of daily life, chemistry is even still more important : I mean in proportion to the relative importance of the arts themselves. The working of metals, an art on which the existence of so many others depend, is indebted to chemistry for all its modern improvements, and may expect to derive thence numerous others of the greatest value and importance. The manufacture of glass, and of the various kinds of porcelain, pottery, &c. (arts which so mainly contribute to our daily comforts and pleasures) are constantly benefiting by the chemical researches of those who are engaged in them, or by the application of those experiments and discoveries, which have been made and recorded by others. The arts of bleaching, dyeing, printing, tanning of leather, &c., are literally so many processes dependent for their success en-

tirely on chemical principles; and if it should be said, that these arts are chéifly ornamental ones, and more subservient to our luxuries than our wants, it may be replied, that a nation in which the ornamental arts of life are not held in high estimation, has not reached its highest point of civilization, and is not soon likely to reach it. In the manufacture of wines, spirits, and fermented liquors in general, chemical principles are obviously of the last importance; and they are even still more so in suggesting the proper use and application of these powerful agents, and in the detection and exposure of those spurious imitations, the effects of which are as injurious as those of the reality are beneficial, when judiciously used.

Finally, the noble art of applying sanative remedies to the diseases incident to the human frame, has already derived incalculable benefit from an alliance with chemical knowledge; and it may be confidently expected every day to derive more and more. How, indeed, should it be otherwise, when it is considered that the human frame may aptly be regarded as a small, but exquisitely contrived laboratory, in which a series of chemical operations are perpetually going on. The concoction of the food, and its conversion, first into blood, and afterwards into the various other matters of which the body is formed, are

all so many operations exclusively dependent on chemical changes and affinities.

I shall close this introductory discourse by relating to you a few anecdotes which have come within my own immediate knowledge, and which seem to me strikingly to illustrate the vast importance of effecting a judicious alliance between chemistry and the various arts of daily life. I might multiply similar facts to an almost endless extent; but I shall content myself with mentioning *one* only, connected with each of the branches of knowledge to which I have just referred.

First, with regard to *agriculture*. It is well known that *lime* forms an excellent manure, and that it is procured for this purpose by burning common chalk or limestone (which is usually a tolerably pure carbonate of lime), and thus dissipating the carbonic acid, and leaving the lime to act immediately on the soil with which it is placed in contact.

I am acquainted with a farmer who, some years ago, went to a considerable expense in erecting lime-kilns, &c., in order to procure manure in the way I have just described; and he used, for the purpose of procuring the lime, a limestone which was very plentiful on his own estate, and which furnished a lime that was, for all common purposes, similar to any other.

After manuring the greater part of his land with the lime thus obtained, he found, to his no small amazement and injury, that, instead of improving his land, he had totally destroyed its power of supporting any vegetation whatever. In the arable land the seeds perished and disappeared; and in the meadow land the grass withered away and died. It turned out that, on inquiring into the exact nature of the limestone he had employed, it contained a portion of *magnesia!* The mystery was solved at once, but not till it was too late. If my friend had been a chemist himself, or had applied to one *before* the mischief was done, instead of *after*, he would certainly have avoided it all. On a chemical examination of the smallest fragment of the stone in question, it would have appeared in a moment that it was totally unfit for the purpose required. There can be little doubt that, if my friend had attended a single course of chemical lectures (or even a single lecture, supposing the earths had happened to have been the subject of that lecture), he would have missed all his disappointment, mortification, and loss.

With respect to the importance of applying chemical principles to the art of manufacturing *fermented liquors*, I will mention that, until within these few years, a disease was prevalent in cyder countries, and more particularly in De-

vonshire, well known by the name of the "*Devonshire cholic*:" so called on account of its being prevalent in that county. It was for a long time considered that this disease arose from some injudicious use of cyder, such as drinking it too new, or in too great quantities, &c ; but this was not generally regarded as a satisfactory explanation of the fact. At length an observant chemist remarked that the manufacturers were in the habit of conducting one part of their process of cyder-making in *leaden vats*. Nothing more was needed to explain the fact. The mallic acid of the apple took up a portion of the lead, which immediately acted on the stomach, as it invariably does, and produced the disease in question. The evil has been since remedied, and the disease has disappeared.

The importance of chemical knowledge to those engaged in the productions of the different *metals* from their native state in the bowels of the earth, is strikingly exemplified by a fact, which is at this moment exhibiting in my native county of Cornwall. They are at present actually working over again some old mines which had been abandoned as exhausted—not for the purpose of detecting any vein or ore which the old miners had overlooked, but for the purpose of obtaining what was formerly cast aside as *refuse*; but which is now found to be incomparably more valuable than

the substance for which they were alone in search in former years. The metal in search of which the mine was originally worked was *tin;* while the ore, which they threw aside as valueless, is *copper!*

In before alluding to the art of making *porcelain*, *pottery*, &c., on which so much of our domestic comfort depends, I have noticed the admirable improvements and discoveries introduced by Mr. Wedgwood, in consequence of his knowledge of chemical science, and his judicious application of that knowledge. It seems needless in this place to do more than mention the name of Sir Humphrey Davy's safety-lamp. There is no hyperbole or exaggeration in saying, that it is annually saving the lives of hundreds of human beings. It only remains, therefore, to refer to the connexion between chemistry and medicine.

The anecdote I shall relate, in order to prove that chemical knowledge is eminently important, and even indispensable, to those who profess to administer *medicines* for the relief of bodily disease, is most striking: I saw, a short time since, a prescription, which consisted of two substances, perfectly innocent, and indeed sanative, when used separately; but which, on being mixed together in the manner directed in the prescription, became decidedly poisonous. Whether this circumstance arose from ignorance, or from carelessness and

mistake, I am not prepared to say; but certain it is, that if these substances had been mixed and compounded agreeable to the prescription, the most serious, if not fatal consequences might have ensued.

LECTURE II.

ATTRACTION OF COHESION, &c.

I PROPOSE, in the present and the following Lectures, to examine into the ultimate nature and qualities of matter in general, as far as these are connected with, and developed by, chemical science. It may be stated as a fact, capable of actual demonstration, that this earth consists of a mass of elementary atoms, which are in themselves *absolutely unchangeable and indivisible;* and that these ultimate atoms are endowed, by their Creator, with certain powers and dispositions, and act according to certain invariable laws, in virtue of which certain unions take place; which unions constitute our world as it exists at the present, or at any given moment, and bring about those various changes and modifications which are from time to time taking place.

Those qualities of matter with which chemistry is chiefly concerned are, *attraction* as it exists between separate atoms of a *similar* kind, or *homogeneous attraction;*—*attraction* as it exists between

separate atoms of a *dissimilar* kind, or *heterogeneous attraction*;—and the different modifications of these, as it regards their force and intensity, and which modifications produce *cohesion*, *solution*, *chrystallization*, and chemical action in general.

In order to distinguish these different kinds of attraction from another kind, which is termed the *attraction of gravitation*, it may be here stated once for all (and the distinction is very important to be remembered), that the latter kind—*the attraction of gravitation*—is exerted at *sensible* distances, and between visible masses of matter of a similar and dissimilar nature, indiscriminately; whereas the different kinds of attraction which are connected with chemical research, exert their influence at *insensible* distances only, and chiefly between the ultimate, invisible, and unchangeable atoms of matter. It is with these latter kinds alone that we are at present concerned.

The simplest effect of attraction is *cohesion*, or the adherence of a quantity of particles together, so as to keep them in an apparently solid mass. The piece of sealing wax which I hold in my hand maintains its present form, or *coheres* together, in virtue of the attraction which exists between the various particles of which it is composed; but it is evident that this form is not necessary to its existence, since I can, in common language,

break it into two or more pieces. But in doing so, I must exert a power stronger than that by which it is held together, and thus overcome the effect of it. In this particular substance, therefore, we may conclude that the *Attraction of Cohesion* is comparatively *weak*. Here is another substance (a piece of iron) which I cannot separate by any mere manual force that I am able to exert upon it: consequently I learn that the attraction existing between the particles of this substance is much *stronger* than that existing between those of the other. And thus it is with every other kind of chemical attraction. Their force varies under various circumstances to an indefinite extent. The effect of cohesive attraction is most strongly exhibited in solids—and in these it is proportioned to their respective densities. In liquids it is seen to act less powerfully; and in aeriform substances it appears to be overcome altogether; since, if they are allowed to escape into open space, they become dissipated, and cannot again be detected.

For instance, if we allow the gas, called Chlorine, or Sulphuretted Hydrogen, or any other offensive gas, to escape from an air-jar, or other situation in which it may have been confined, we shall perceive in a very short time that it will become mixed with the whole atmosphere of the apartment in which the experiment has been made;

thus proving to us that the particles of which the gas was composed had separated from each other and distributed themselves equally in all directions.

Again, if we sublime camphor by heating it, we shall perceive the pungent smell of the vapour, while it continues in this state, not in one particular spot, but universally diffused, as in the former instance, throughout the whole apartment.

If we mix five parts of spirits of wine, and three of aqua-fortis together in a Florence flask, the two liquids will gradually assume the aeriform state, and become an inflammable vapour, which will escape from the neck of the flask: this vapour will neither raise in a column, nor will the particles keep together by any cohesive force, but as soon as formed they will begin to separate; and in two or three seconds the vapour will be found to have mixed completely with the surrounding atmosphere, as may be shewn by presenting a lighted taper near to the flask, when the particles will be seen to inflame in a space equal to several feet about the mouth from whence it escapes. This is a very pleasing experiment; but the quantities of the mixture should never exceed *five drams* of spirits of wine to *three* of *aqua-fortis;* and the neck of the flask should be rather *large*, to admit the easy passage of the vapour.

Chemical attraction, whether of cohesion or of affinity, acts only at *insensible* distances, and it must be understood that the term "insensible"

is intended to refer merely to our imperfect human perceptions, and is not meant to indicate any *determinate* distance. In point of fact, chemical attraction of both kinds acts with greater or less power, in proportion to the distances from each other at which the particles may happen to be placed on which it is acting; though this *difference* of distance cannot be traced by our bodily senses, and is only to be judged of by its visible effects. Moreover, when we speak of particles, or even of ultimate atoms, as being *in contact*, it must be understood as a relative term merely; for it is probable that *actual contact* has no existence whatever in nature. To bestow further consideration on this part of our subject at present, would be out of place; but I have considered it useful to hint thus much even in the present early stage of our enquiry.

The most important light in which Cohesion is to be regarded by the Chemist, is, in that of a force which modifies, and in many instances counteracts that of chemical or elective affinity; and thus altogether prevents chemical action from taking place, until its influence is in some degree overcome; for elective affinity may be considered as inefficient nearly, if not exactly in proportion as the affinity of Cohesion is strong. The means and the effect of overcoming this power are therefore next to be considered. The commonest

means are, first, *mechanical ones*—such as *filing, grinding, pulverising, &c.*; secondly, by *heat*—and thirdly, by *solution.* In some instances, even a minuter division than can be obtained in either of these ways is necessary before certain bodies can be chemically acted on by others, which have nevertheless a strong affinity for them; I mean by *precipitation.* Silex, for example, in the state of rock crystal, is not in the slightest degree acted upon even by boiling in liquid potash; and it remains insensible to the influence of that substance even when submitted to it in the form of a finely divided *powder;* but if it be *precipitated* from a state of chemical solution with some other substance, and *then* submitted to the action of potash, that solvent readily takes it up, and unites with it chemically. If we take a *solid* piece of metal and throw it into a vessel containing chlorine gas, *very little,* if any action will be perceived; but if we previously *grind* or *powder* it, it will *take fire* the instant it is so introduced; proving that this previous division is necessary to overcome the force of Cohesion, and enable the chlorine to combine with the metal. Antimony succeeds best for this experiment; but the other metals will equally answer the object if moderately heated before they are submitted to the action of this gas.

Lycopodium will scarcely burn at all, although finely pulverized, when its particles are suffered to

exert the common force of gravitation among themselves, as may be shewn by trying to ignite it when lying in heaps or parcels; but if we throw it into the atmosphere, and by this means mechanically force or separate the particles from each other, it will readily inflame and the whole will be consumed. Pulverized rosin, &c. will exhibit the same phenomenon, and confirm the same law.

Heat is the grand *antagonist* to the *attraction* of *cohesion*. In almost all natural changes its influence is important; and in chemical inquiry it is by far the most powerful and valuable agent we possess for effecting a *separation* of the particles of matter. We shall see its action in overcoming cohesion, in a variety of different ways, when we come to treat of the subject of heat or caloric as a separate theme of inquiry.

The next power is that of *solution*, which is a separation of the particles of matter effected by the intervention of a fluid having a stronger affinity or attraction for these particles than they possess amongst themselves; and consequently disunite them, by producing a division equally through the whole extent of fluid, and a proportionate separation from each other.

If we mix together crystals *of dry* tartaric acid and carbonate of soda, *no action* will be perceived, or will in fact take place; for these two bodies remain mixed in their dry state for months, and

even years, without combination or decomposition, as may be seen in the common "saline powder" or "Seidlitz powder" of the shops. But if we *dissolve* them separately, and then mix the solutions, *violent action* will be produced. They will combine together chemically, forming a salt called tartrate of soda, carbonic acid gas will be liberated, producing, with the water employed in the solution, the soda water so commonly used in the present day. Again, strong *concentrated* solution of nitric acid, when poured on quicksilver, produces little or no effect on it; but if water be added, so as to effect a further solution of the nitric acid, considerable action will ensue. So also strong oil of vitriol poured on iron filings has little action until water be added.

I must here remark that *solution* is very different from mere *mixture*, a distinction that should be attended to by the student. *Solution* is a *chemical* combination between the fluid and any substance that may be dissolved in it; whereas *mixture* is simply a separation of the partricles of matter by a mechanical power Portions of the substance float about in the fluid it is mixed with, but they do not combine with it; and these portions will, if the mixture remains at rest, fall to the bottom, or rise to the surface, according to their relative specific gravity as compared with that of the fluid. This may be shewn by the

following experiment: and the difference between solution and mixture will also be distinctly *seen.*

Put into a glass vessel containing water a few grains of sugar of lead, and stir them together, with a glass or other rod, the water will soon become turbid, in consequence of the sugar of lead, being *insoluble* in that fluid; and simply a *mixture* of the particles with the water will take place: if the water be minutely examined, these particles may be perceived floating in it; and they will ultimately, if left to themselves, fall to the bottom. If to this *milky* fluid be now added a few drops of aqua-fortis, it will instantly become *perfectly clear* and transparent, and now not the minutest portion of the lead can be perceived in it. In the first instance then it was only a *mixture;* in the latter a *perfect solution;* because the combination of lead and aqua fortis is soluble in water, whereas the sugar of lead is not so. Again, mix chalk and water together, and the fluid so produced will be *turbid;* but if you add a few drops of spirits of salts, it will become perfectly *transparent.*

So important is *solution* in chemical operations, that it was once supposed to be *indispensably necessary* to enable bodies to unite with each other. This, however, is not the case.

The attraction of cohesion causes quicksilver to assume a *convex* surface when placed in a

glass vessel, and a *concave* surface when in a *metal* one.

It is this property which causes capillary attraction; and it is a modification of this latter which causes two pieces of cork, or any other light substances, to approach and touch each other when placed on the surface of a vessel of water, and not *gravitation* as is generally stated.

The particles of the water nearest to the corks are attracted to them, and the arrangement of the intermediate particles causes them to approach, and at length touch.

If you place lightly and carefully two pieces of cork *perfectly dry* on the surface of a small vessel of water, and then drive one piece towards the other, the one floating at liberty will recede from the approaching one; but if you now wet them, or either of them, they will be seen to approach each other; and you will observe in the *first* instance, that the surface of the water forms a *convex* curve round the cork, and in the *second* a *concave one*.

The respective force of cohesion inherent in different bodies is well known, and in the present state of the science it seems to me of the highest importance to inquire *why* this protractive power is greater in *one* substance than in *another?* I have studied this point of inquiry with some attention, and shall state my views respecting it hereafter.

Plate 1.

Fig. 1.

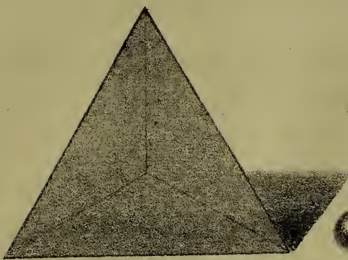


Fig. 4.

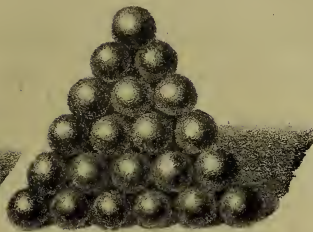


Fig. 2.

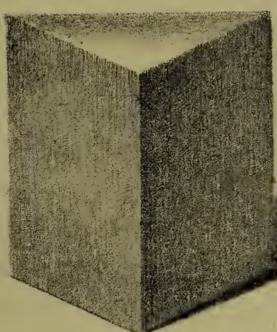


Fig. 5

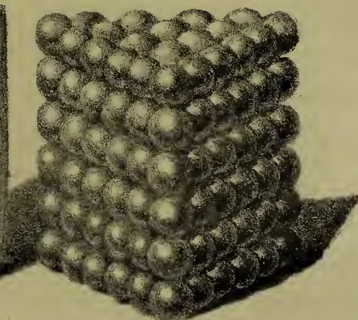


Fig. 3

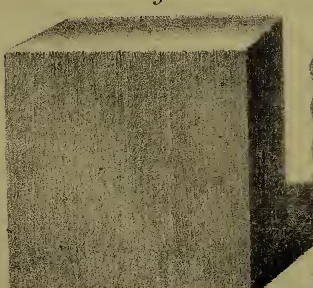
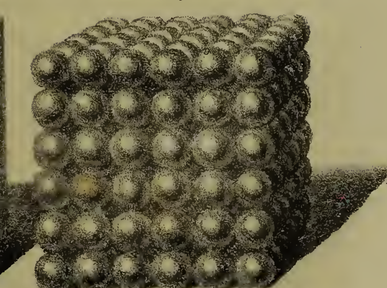


Fig. 6.



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We shall devote the remainder of this lecture to the interesting subject of crystallization; considering *that* to be the most direct and necessary, as well as the most striking consequence of the attraction of cohesion, or homogeneous attraction.

Crystallization may be defined to be that regular arrangement which the particles of a great proportion of inorganic matter are disposed to assume, in virtue of that peculiar force which is perpetually acting upon them under the name of attraction. And this force performs its office more or less perfectly, in proportion as the particles on which it is acting are left free to move amongst themselves, when the counter-force (of heat, or whatever it may have been), which held them asunder, ceases to operate. If, by means of heat, we reduce camphor to a state of vapour, or fume, and collect this fume in an empty glass-vessel, as this matter cools (or, in other words, as the heat which kept the particles of it asunder escapes, and leaves them to assume what arrangement they please), that arrangement will invariably be a *regular* one, and what are called *crystals* will be formed on the sides of the glass. To take a still more familiar instance, if we dissolve common salt in common water, we so divide the particles of salt from each other, by means of the water which interposes between them, that they are no longer able to exert their natural influence

upon each other. But if we abstract a portion of this water, we enable them to approach nearer and nearer, according to the relative quantity that we abstract, till at length, these particles arrive within the sphere of each others attraction; they meet, and having full liberty to do so exactly according to their natural dispositions, they assume regular forms, to which forms we give the name of crystals, as before. And thus it is with a vast variety of other substances, namely, the metals, sulphur, various earths, all the chemical products termed salts, water, &c. &c. All these, if the matter of heat be abstracted from them to a certain point, and their particles are at the same time free to move among themselves, assume *regular geometrical forms;* in other words, they *crystallize.*

I shall cursorily notice a few of the circumstances which influence crystallization; and then proceed briefly to examine the laws by which its different characters seem to be determined.

Freedom of motion being the most essential condition required previous to crystallization, it is obvious that, before matters can assume the form of crystals, they must be brought to the state of either a *liquid,* or an *aeriform fluid;* and it follows also, that the more *slowly* the heat, or whatever other matter be abstracted which kept them in either of those states, the more regular and determinate will be the form assumed.

Crystallization is influenced by various other circumstances; such as the attraction of the crystallizing body for water; the presence of atmospheric air, of light, &c. The crystallization of salts, for example, depends in a great measure on the water they take up, and this is considered to be the case with respect to all crystals which are transparent. The water thus taken up by crystals is called their *water of crystallization;* and when this water is driven off from them by heat, they cease to retain their regular form, and fall into a confused mass; as in the case of sulphate of lime, which contains 20 per cent. of water, but which leaves it when heated to redress, and the crystals lose their regular form, and become the white impalpable powder termed Plaster of Paris. In other cases, salts are found not to leave the water which holds them in solution, and consequently not to crystallize, without the presence of a substance which has a stronger affinity for water than they have: thus alcohol, having a very strong affinity for water, will sometimes cause crystals to form when nothing else will. Crystallization is also frequently produced, or at least accelerated, by the introduction of a substance on which the crystals may form or arrange themselses. An already formed crystal, of similar kind with those required to be formed, is frequently more effectual than any thing else in cases of this kind. And

there are instances in which, when two different salts are contained in the same solution, that will crystallize first, an already formed crystal of which has been introduced. It happens, also, that when two salts, which are not equally soluble in water, exist in a state of solution together, the one which is least soluble will separate from the other spontaneously, and form crystals, leaving the other in solution till more of the water is evaporated. The presence of air (as before stated) and of light, are also sometimes influential in accelerating or modifying the formation of crystals.

To shew the influence of *light*, place a solution of a salt in a dark room, and while it remains uncrystallized, let a ray be admitted, and suffered to fall on one side of the vessel containing the solution, crystals will begin to form on *that side*, and the whole will soon form about those first produced. Acetate of lead and fluate of lime assume beautiful appearances when under the partial influence of light; crystals will grow, as it were, towards the light, and assume various pleasing forms. The camphor jars in druggists' windows shew the influence of light. But although light hastens, it is not in all cases absolutely necessary to crystallization.

A *crystal* or *nucleus* thrown into a solution of some salts, instantly produces crystallization.

Make a strong solution of Glauber's Salt in boiling water, and while still hot, pour it into a Florence flask and cork it up, and a vacuum will be formed by the condensation of the steam above the surface of the solution within the flask, when the solution is perfectly cold. Now very *gently* withdraw the cork, and introduce a crystal of the same salt into it, and the whole will instantly shoot into crystals, commencing from the crystal so introduced.

Not only a crystal of the same kind, but any *solid* substance or nucleus will always hasten crystallization ; and it will invariably commence from, or around this substance. It is by means of threads introduced into solutions of sugar-candy, of verdigrease, &c. that regular masses of crystals of these susbtances are formed, which we see in the shops, &c. &c. This property of crystals to deposit themselves about a nucleus may be shown to a very pleasing effect, by placing substances of certain forms into solutions of salts. Imitations of certain minerals, or natural crystals may be thus produced, of very beautiful appearance, and so exact in their resemblance to natural ones, that the difference cannot be discovered without minute examination. They are thus formed :—Take a blacksmith's cinder, or what is commonly known by the name of a "*clinker*," and place it into a hot solution of

alum in water, in the proportions of about half a pound of the former to a pint of the latter. In a short time it may be taken out of the solution, and the crystals of alum will be found to have deposited themselves about it, in perfect immitation of natural quartz. Weaker solutions than the above succeed rather better; but they require a much longer time to form: these specimens have the exact appearance of mineral productions, and may be varied in colour, by substituting for the alum, blue-stone, copperas, &c.: little wire baskets, suspended in this solution, become studded over with very brilliant crystals. The solution should be very strong for this purpose, and the basket only suspended in it for a short time; perhaps five or ten minutes, according to the fancy of the operator.

The influence of *atmospheric air* has also considerable effect; as may be shewn by *suddenly* withdrawing the cork from a flask or phial of a strong solution of Glauber's salt, prepared in the way that was directed for the first experiment. On *thus* withdrawing the cork, and admitting the atmospheric air to press on the surface of the solution, the whole will instantly crystallize.

This effect of atmospheric air has been ascribed to the *mechanical agitation* it produces on the surface of the solution; and Dr. Ure has satisfactorily shown that this is the case. Electricity has

also some effect in producing crystallization. And, perhaps, the agitation occasioned by the sudden admission of the atmosphere on the surface of these solutions causes crystallization, in consequence of its thus exciting electrical action.

With respect to the external forms of crystals, the only satisfactory practical researches which have been made, are those of Romé de Lisle and the Abbé Haûy. It is known that different substances crystallize under the same external form. Common salt, for instance, takes the form of a cube, as likewise does the Derbyshire spar. Nitre crystallizes in six-sided prisms, and Epsom salt in four-sided prisms, &c. But it sometimes happens, that the fluate of lime and carbonate of lime, assumes a variety of different ones. These, with other circumstances, tended to destroy all the theories respecting the laws of crystallization, until the Abbé Haûy established his ingenious inquiries on this subject. He at first was enabled to demonstrate, that all the known forms of crystals are reducible to *six primitive forms*, to which the others are secondary, and he has shown how the one may be produced from the other. These six forms, he afterwards proved, could be reduced to *three*, from which all the various figures assumed by crystals could be framed; viz., the *tetraëdron*, fig. 1.; *simple prism*, fig. 2.; and

the cube, fig. 3, plate, 1. These primitive forms were obtained by splitting crystals, layer off layer, till at last, they could be separated no further. When the operation had been carried thus far, the last form was considered the primitive one.

Some of the secondary forms are considered to take place in consequence of the layers of ultimate particles decreasing regularly on the primitive. Thus, supposing the primitive form to be a cube, a series of decreasing layers of cubic particles upon its several faces, will produce a dodecaëdron, if the decrement be upon the edges; but it will become an octoëdron, if the decrement take place on the angles: and, by irregular and mixed decrements, a great variety of form would ensue. It so happens, however, that in the crystallization of some substances, appearances occur, which Haûy's theory will not satisfactorily explain.

As I conceive this to be a subject of the highest interest and importance, I shall consider it again at some length in my next lecture; for I am satisfied that, if the law which governs crystallization can be discovered, it will lead to the development and elucidation of the causes of many other phenomena, which have hitherto baffled the examination, and set at defiance the conjectures of the most distinguished philosophers, not only of the present, but of all past times.

LECTURE III.

CRYSTALLIZATION.

I STATED in my last Lecture that the theory of crystallization, advanced by the Abbé Haüy, has been found to be incapable of accounting for all the various figures which are obtained by splitting and dissecting crystals. A more simple and satisfactory theory, therefore, being obviously desirable, I shall not apologize for laying before you the result of some investigations which I have lately been engaged in, on this most difficult and interesting subject.

The basis of Haüy's theory is, that the forms of all crystals are produced by certain arrangements of *three* primitive figures, namely, the tetraedron, plate 1, fig. 1; the simple prism, plate 1, fig. 2; and the cube, plate 1, fig. 3; and that these figures, or primitive molecules, not only form every crystal in nature, but that, by a certain arrangement with respect to each other, they must completely fill space. It appears in the examination

of certain crystals, that not only the tetraedron, but the octoedron, the latter of which by Haüy's theory is formed from cubes, are found together in the same crystal. Now, as cubes and tetraedra cannot, by any possible arrangement, be adapted to each other so as to fill space, it follows, from these circumstances, connected with others, that the theory is by no means satisfactory. In order to remove this difficulty and objection to Haüy's theory, Dr. Wollaston has assumed that the primitive molecules consist also of *three*, *viz.* the sphere, the spheroid, and the oblong sphere or elipsoid; and he states that it is under certain arrangements of one or other of these, that all crystals assume their external figure and appearance.

I adopt, as a general proposition, the most simple of those laws by which the operations of nature are governed; and since nature never employs two or more means to effect an end when *one* is sufficient, I presume that it will not be regarded as philosophical to adopt a gratuitous supposition in order to account for a certain phenomenon, when that supposition is found not to hold good in other similar instances.

I intend these two foregoing remarks to apply to the essential points in all the theories of crystallization I have yet met with, and at the same time to refer them to the general inductions which I am about to offer, as the results of recent expe-

riments and investigations on this subject; for to suppose that the primitive atoms of matter or molecules of crystals are of *three* different forms, appears to me to be at variance with the known simplicity and harmony of nature; and to presume that the primitive molecules of crystals must, in every arrangement, actually fill space, is contrary to those known facts with which every one is acquainted.

Perhaps it will be regarded as unnecessary to admit either of these suppositions, if it can be shown that *all* the known forms of crystals may be produced by certain arrangements of *one* primitive form; and more particularly if one unchangeable law can be pointed out, through which these atoms are *compelled* to form certain arrangements and to assume definite figures, and in virtue of which all the varied forms of crystals may be produced. The limited time which I am allowed in a lecture-room precludes my entering into all the various facts and reasonings which have led me to the following conclusions, and consequently to doubt the correctness of the present theories of crystallization; or from doing more than laying before you these conclusions, which perhaps may lead to a more rational system, or in conformity with which I conceive that such a theory must be constructed. I shall therefore proceed to state them at once.

First, then, I believe that every identical or pri-

mary atom composing the material universe is of a given figure. 2dly. That such elementary figure is the most *simple possible*, and, at the same time, the most *perfect* we are acquainted with—namely, *a sphere*. 3dly. That every primary atom is absolutely *unchangeable* and indivisible, and that the fraction of an atom cannot occur. 4thly. That every primary atom is of one and the same size or bulk. 5thly. That every primary atom of every simple body, or class, is endued with certain properties *which never change*; that whatever changes may take place in their order of juxta-position, or of numerical aggregation (notwithstanding the vicissitudes of form which decomposition and new combinations induce) that, in fact, the primitive atoms remain subservient to the same laws, and preserve all the qualities peculiar to themselves individually, under whatever circumstances they may be placed.

In conformity with the foregoing views, I am compelled to doubt the correctness of any hypothesis which cannot be made to comprize all these phenomena; and, in constructing my own hypothesis, I willingly reject every thing which cannot be made so to agree.

I have stated my belief, that ultimate atoms are absolutely indivisible and unchangeable: from this it results, that all combinations of them must take place under some *mechanical* form; and, in fact, that all arrangements connected with matter, and

producing its various changes, must be mechanical.

The cracking of basaltic rocks into hexagonal prisms takes place from a mechanical arrangement which compels the particles to separate at definite angles. The hexagonal arrangement of the honeycomb (which has obtained for the little insect who forms it the title of a "profound mathematician")—the hexagonal subdivisions in the pine cone, pine apple, some tortoise-shells, &c. have been all demonstrated (by that accurate observer of natural phenomena, Sir Anthony Carlisle, in his Lectures before the College of Surgeons, in the year 1818) to result from this arrangement existing among the particles of which those objects are composed.

Mechanical arrangement, however, is the *effect* of some *primary cause*, which compels certain arrangement to take place amongst those particles or atoms which compose all material substances. To discover the *cause* by which these effects are regulated, seems to be the sole means of constructing a theory which shall satisfactorily account for the phenomena of crystals.

Various saline and other bodies crystallize into especial figures; but every particular saline or other body invariably crystallizes in the same identical form. Alum, for example, invariably crys-

tallizes into octoedra, Epsom salts into four-sided prisms, nitre into six-sided prisms, common salt into cubes, &c.; but not one of these salts ever takes the form of another. From this it is reasonable to infer, that the figure assumed by each is the natural and necessary result of a certain unchangeable law or laws, acting on the ultimate atoms of which these compounds are formed: else why does not sea-salt sometimes crystallize into six-sided prisms, nitre into cubes, Epsom salts into octoedra, &c.? Now the leading question of philosophical interest and of theoretical importance is that which regards the nature of this controlling law, or directing power. That it is unchangeable is certain, because its results are invariable; and it must also be an inherent property of matter, since the property of ultimate atoms can never change or be destroyed.

I have stated my belief that *all* ultimate atoms, of whatever kind, are of *one* form and *one* size; and that that form is *the sphere*, because the sphere is the most simple and available of all other forms. Now if I can demonstrate that all the known figures of crystals may be formed by a mechanical arrangement of spheres, without having recourse to various, or an unlimited number of molecular figures, I suppose there will be no presumption in asserting, that the theory will be more likely to be true, than that which is compelled to have re-

course to a *multiplication of figures* and forms, and, consequently, of directing laws. Whether the one which may be constructed on the principles which I have laid down be correct or not, I shall leave for others to determine. Indeed, I shall leave the final construction and perfection of such a theory itself to others, at least for the present, on account of its demanding more time than I am able at present to devote to it. In the meanwhile, as the furtherance of the true interests of science is my sole object in these Lectures, and in the studies which I have been induced to pursue in the course of preparing them, I shall plainly state my views on this subject, leaving the further development of those views (supposing them to be found worthy of further development) to those whose pursuits are more immediately directed to such ends. I clearly see that a perfect and incontrovertible theory of crystallization *may* be formed on the principles I am referring to; and, if such a theory should *not* be so formed, mathematically and demonstrably complete in all its parts, I pledge myself at a future period to supply the defects of my present hasty sketch.

I shall, in the first place, shew the manner of the arrangement which we are now considering, and then proceed to examine the law which seems to direct that arrangement.

1st. That the primitive forms of Haüy are capable of being formed by a certain arrangement of spheres, which may be seen in the diagrams, in plate 1. In figures 1, 2, 3, we have representations of these three primitive forms; and in figures 4, 5, 6, we have the same formed of spheres, showing their peculiar and specific necessary arrangement. In figure 4, the spheres are placed in close contact in every direction, occupying (when taken collectively) the least possible space, and forming angles of 60°. In figure 5, the base is obedient to the same arrangement, forming angles of 60°: but the elevation is different, rising perpendicularly, and forming angles of 90°; a given number of spheres in this case occupying more space. In figure 6, the angles, both of the base and elevation, are all 90; the spheres occupying still more space than in either of the preceding arrangements.

I do not conceive it necessary here to proceed farther in shewing, that, by certain mechanical arrangement, spheres may be made to form all the known figures which crystals assume, as this may easily be imagined, but shall proceed to state my views as to those peculiar properties of matter, in virtue of which its ultimate atoms are *compelled* to form these arrangements; and, in particular, those express arrangements which we have just examined; and the various forms we are at present contemplating, under the name of crystallization.

Previous to doing which, however, I think it desirable to say a few words relative to one of those propositions with which I set out; *viz.* the 5th. I have there stated my belief, that the ultimate atoms of matter remain subservient to the same laws, and preserve the same qualities and habitudes, under whatever circumstances they may be placed; that, in fact, the laws which they obey are unchangeable and unalienable. This may be contrary to some received opinions, and at variance with the supposed evidence of our senses, and therefore it is proper for me to explain the manner in which I conceive these apparent deceptions to take place; because the law we are about to examine, if necessarily inherent in matter, must be a property of every ultimate atom of every kind or element; and, therefore, I wish to make a few observations on this subject, before I proceed to submit to you what I conceive this property to be.

Every simple substance is endued with certain essential properties. Some are common to every element, such as magnitude, extension, &c.; but every element possesses other properties which are peculiar to the *species* itself.

The visible properties which are *peculiar* to a simple body, constitute the characters by which we identify it, and those which are *common* to all are less attended to.

Some of the essential and specific properties of bodies are more evident to our senses than others; and some of the latter are entirely eclipsed or hidden from our senses, by the powerful influence of the former, which may be termed the *apparent* or *visible* properties of bodies.

All the arrangements, or combinations of the ultimate atoms of matter are effected by the action of certain inherent properties. Some of these properties which are engaged in and influence this union, become balanced or neutralized in combination: for while these peculiar properties preserve the combination which they have produced, they are unable to affect our senses; and consequently they thus allow some previously hidden properties to become the visible ones, and thus new properties seem to be formed by chemical combination.

No new property can be added to, nor can any be taken from the ultimate atoms of matter, nor can any of their intrinsic properties, whether visible or invisible, be destroyed. In fact, if they *were* destroyed, it would of course require a new act of the Creative Will, to form every new arrangement of the material universe: which consideration alone is sufficient to convince us that no such vacillation takes place. The laws of nature are unchangeable, and their corresponding results are unvarying: therefore, whenever the *evidence* (as we call it) of our senses

is at variance with this doctrine, we may justly regard it as either unfounded, or consider it (which is a more philosophical mode of solving the difficulty) purposely so arranged for our especial accommodation and use. We are to accept the experience arising from the evidence of our senses, not as the sole rule of our *belief*, but only of our *practice*, where it relates to the common business of life.

The facts which I refer to, relative to certain apparently contradictory effects which are occasionally produced on our senses, and shown by our instruments, are when bodies, consisting of two or more elements, are totally changed in their characters and qualities by the addition of a third element, or by an additional proportion of either of the same; while none of the characters or qualities so acquired appeared to belong in any degree to the element which has been thus added, or to either of them, previous to combination. In consequence of facts of this kind perpetually occurring, it is said that *chemical action* (as it is unphilosophically called) is capable of producing or engendering certain qualities or properties which *did not previously exist* in the body acted on, or in the elements composing it. This is a gross error; but, perhaps, it is an error of *expression* only.

The results of the union of simple bodies (so called) under certain circumstances, are changes in the

external appearances of the new compound; which appearances are the necessary consequences of those immutable laws which have been impressed, once and for ever, on the *elements* of which the compound in question consists. *Carbon*, for example—supposing it to be a simple element—possesses certain qualities which can never be separated from it. Some of these properties are evident to our senses, from their effects; but others, which it also possesses, are not evident to our senses in their effects, until we combine it with another element. *Oxygen*, also—supposing *that* to be a simple element—possesses its peculiar qualities; but some of them are only to be brought out, so as to be active upon our senses, by means of a union with something else. Oxygen is a supporter of combustion, but is itself incapable of inflammation; while carbon is not a supporter of combustion, but is inflammable. Now, if we combine these two elements in the proportion of one atom of oxygen to one of carbon, some of the visible properties of the carbon are counterbalanced by those of the oxygen, and *vice versâ*. (The mixture thus formed is carbonic-oxide).

Let us unite a second proportion of oxygen to the compound just described, and we shall find altogether new and different properties; not produced, but *evolved*. A mixture of oxygen and carbon, in the proportions of two of the former

to one of the latter, forms carbonic *acid ;* which is neither inflammable itself, nor will it support combustion : though of the two elements of which carbonic acid consists, one is the most powerful known supporter of combustion, and the other among the most active combustibles. In this case, the balance between these particular opposing properties of the different ultimate atoms seems to be complete, and their corresponding external effects are neutralized; and other properties, which before were hidden from our senses, now are enabled to act, and, in fact, become the prominent ones of the compound. But shall we say that the first are therefore destroyed? Surely not; for if the carbonic *oxide*, alluded to above, had been simply *mixed* with another proportion of oxygen (instead of their being what is called chemically combined), the result would have been, a compound exhibiting in the highest possible degree the qualities of *both* the elements ; *viz.* an *explosive* substance, possessing a highly inflammable quality, and, at the same time, a power of supporting combustion from within itself; whereas carbonic *acid* evinces properties which could not be discovered, either in oxygen, carbon, or carbonic *oxide :* yet these properties or qualities are not newly created or produced, but simply liberated.

The various effects of chemical action on bodies will be considered in our next lecture. I have

hinted thus far, however, in this place, for reasons which will be seen hereafter.

What the property or law is, in virtue of which ultimate atoms act on each other, must now be inquired into; and more particularly, in what manner this property acts in regard to the various phenomena of crystallization. I must repeat, that the limits of a public lecture preclude me from going at any length into the arguments and experiments which have led me to form my views on this most difficult and important subject; but if those views are capable of satisfactorily accounting for *all* the effects to which they are applicable, I suppose it will not be thought presumptuous in me to announce them, leaving to another occasion (if my pursuits should permit me to do so at all) the argumentative and demonstrative part of the subject.

I will at once, then, state my belief, 1stly, That *all the ultimate atoms of the same element* (in addition to the properties before enumerated) *are mutually* REPELLENT ; in other words, *that every individual atom possesses the quality of receding from, or repelling every other atom of the* SAME ELEMENT : and, 2dly, that *every ultimate atom of every element is* ATTRACTIVE *of every ultimate atom of every other element* DISSIMILAR *from itself;* or in other words, *possesses a tendency to unite with it;* and that it is in virtue of this law that all combination or de-

composition is effected. It will probably occur to you that this law, supposing it to exist, is exactly similar to that which is certainly known to exist between all substances which are in a *similar* or a *different* electrical state. All bodies similarly electrified repel each other; and all bodies dissimilarly electrified attract each other. Whether or not one of these laws is a modification of the other, and whether attraction and repulsion are not *identical*, I shall not now inquire, though I may state, in passing, that I have strong reason to believe that they are, in fact, modifications of each other, and the result of one and the same elementary cause.

Fearing that some may suspect the truth of these peculiar laws, which I have just presumed as appertaining to the ultimate atoms of matter, and thence that of my theory altogether, I would observe here, that it matters not to our present enquiry what the true nature of this property is which disposes and effects combination between the elements of nature, since we know, to an absolute certainty, that *some power* must bring them together, and keep them in that situation, and that this power is, and must be *balanced* by some opposing force, or in some way or other neutralized, whenever chemical combination has taken place; for chemical compounds are invariably definite ones, and it is in certain proportions only that elements will combine at all. This

property, whatever it may be, being a primary property of the ultimate atoms of bodies, can never change or be destroyed; and therefore, as I have just stated, must be simply balanced by some counteracting force inherent in the elements themselves. And since the ultimate atoms are *unchangeable* and *indivisible*, it follows also as a demonstrable proof, that their peculiar habitudes, whatever they may be, can only be acted on by mechanical aggregation of the atoms, and juxtaposition with respect to each other; therefore, this balance of power just alluded to, must be effected by mechanical arrangement. And hence, the reason why crystals, which are in fact no more or less than solid forms of chemical compounds, assume various and definite external figures. We will consent, for the better demonstration of the subject, to call this power *attraction* and *repulsion*, exerting itself as I have before stated, and I will proceed to shew how I conceive these respective forces are balanced by mechanical arrangement, and how certain angles in crystallizable bodies are, and must be produced. In order to make my explanation more clear and satisfactory, I have constructed for this purpose a moveable diagram, by means of which I shall offer to your view what I may perhaps venture to call enlarged representations or images of the ultimate atoms of matter.

In the first place, we will suppose a certain

Plate 2.

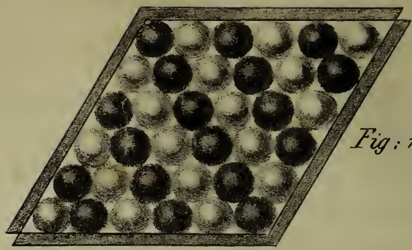

Fig: 1.

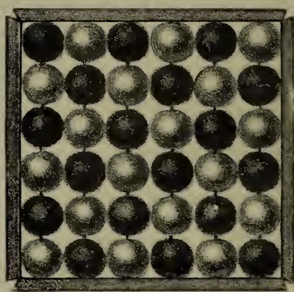

Fig: 2.

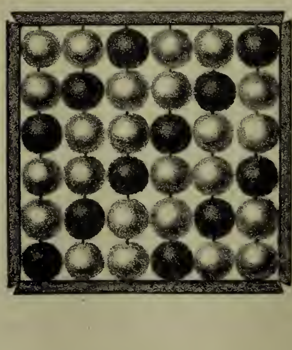

Fig 3

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number of ultimate atoms of two different elements, meeting together in the proportion of *one* to *one*, as seen in plate 2, fig. 1, and we will suppose these atoms endued, respectively, with the powers or properties that I have assigned to them. The question is, what definite form would they necessarily assume under these circumstances? Not what form would they be *likely* to assume? but what form *must* they necessarily assume? Let us suppose the forces to which I have alluded suddenly to act on the atoms respectively, and the answer will be given; for the white spheres would repel each other and attract the black, and the black would repel each other and attract the white, until equal distances were produced between them, and consequently a balance of opposing forces thus effected, the necessary consequence of which would be, a total change of arrangement, and a *definite form* would necessarily be assumed, as is seen in plate 2, fig. 2.

Thus far of *theory*—or of what ought to take place, or must take place, according to my views of the primary laws which direct the ultimate atoms of matter. When I add that, as far as we are acquainted with the composition of certain crystallizing bodies, a compound of one atom of one element to one atom of another does, in point of fact, crystallize in the figure which I have supposed that it must assume, if my premises are

correct, it will perhaps not be deemed presumptuous in me to attach some importance to the circumstance.

It is obvious, also, that this definite and regular arrangement of the atoms, with respect to each other, must still obtain, even should they be removed farther from each other than we will suppose them to be when in a state of perfect crystallization, by the intervention of a solvent, in the form of heat, or any other fluid; and that immediately on the abstraction of that solvent they would again resume their fixed figure. I do not mean that in all cases this figure must be *visible*, because many circumstances may tend to throw the mass formed by the union, although in minute and perfect cubes, into a state of apparent confusion. But, nevertheless, where the atoms are allowed to approach each other slowly, a regular figure to an almost unlimited size may be obtained. And I repeat, that in the case of a union of one atom of one element to one of another, that figure must be in every crystallization, and therefore is a regular one, presenting equal angles of ninety degrees.

From this it appears, that equal distribution, and consequently a specific and definite external figure, must always be the result of these laws, if they direct the ultimate atoms of matter, and are placed within the sphere of each other's

action, so as to effect a perfect balance of opposing forces.

Taking another step in our illustration of this important subject, let us use the same diagram, to shew what will be the figure necessarily assumed by the union of certain ultimate atoms in different proportions from the foregoing. Let us suppose a combination of elements in the proportion of *two* to *one*. We shall find that in endeavouring, in the first place, mechanically to produce equal distribution, while we confine the spheres within this figure of a square we cannot succeed. See plate 2, fig. 3. But let our respective laws of attraction and repulsion act in the present union of atoms, as they did in the previous union of one to one, and we shall find that a new figure will necessarily be formed, in which there is an equal distribution of the different atoms—each black one being surrounded by six whites; and the gross figure thus formed will assume angles of 60 and 120 degrees. Let me here add, that compounds which are known to include a proportion of two atoms of one element to one of another, do, in point of fact, crystallize in this form.

Let us now, by means of the same instrument which we have used in the two previous instances, combine atoms in the proportion of *three* of one kind to *one* of another. We shall find in this instance that we obtain precisely the same form, as

far as the illustrative powers of this instrument goes, as we did in the last compound of two to one.

I confess that, when I first observed this, I was not a little puzzled, because for the moment I had forgotten that this instrument is adapted to shew, and can only shew, the *bases* of the figures which the combinations in question will give. And to suppose that *different* proportions of ultimate atoms, acting under certain definite and unchangeable laws, could produce precisely *the same* figure, seemed directly at variance with the principles which I had adopted, and in conformity with which I was determined to prosecute my inquiries, if I prosecuted them at all. It presently occurred to me, however, that my instrument could shew no more than the *base* of the figure required; that is to say, it could only afford me an image or representation, on a large scale, of a *single layer* of atoms. The *elevation* might or might not be perpendicular to this base, or first layer, according as the forces impressed on the said atoms would act.

In order to shew how these forces will act in regard to the elevation, we must recur for a moment to the *first compound* which we examined; namely, that consisting of equal proportions of one atom to one. In this instance the elevation would be perpendicular; for supposing the first

Plate, 3.

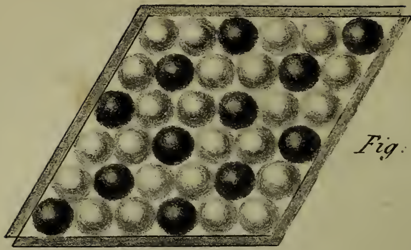

Fig: 1

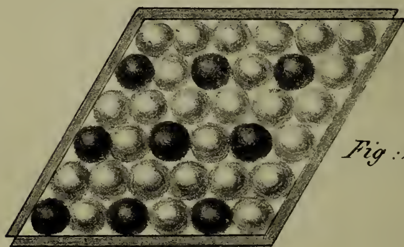

Fig: 2

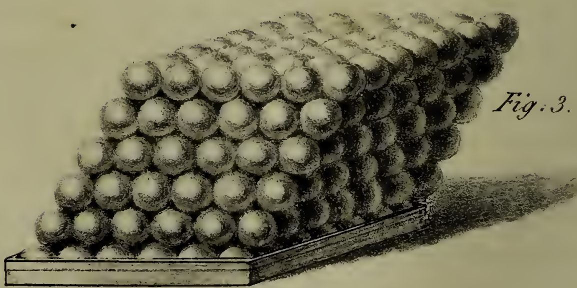

Fig: 3.

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layer of atoms to be disposed according to the principles I have laid down, as seen in plate 2, fig. 2, the next set of atoms about to dispose themselves would each be compelled, by the counter-balancing forces of attraction and repulsion, to be fixed or rest perpendicularly on an *atom* of a different nature from itself: thus, each atom represented by the black in the figure would rest perpendicularly on the centre of a white, and each white perpendicularly on a black; consequently, the elevation, to whatever extent it might proceed, would be perpendicular to the base, as is seen in the diagram, plate 1, fig. 6. The smallest division resulting then from this compound would be *the cube.*

If we now examine the *second* perfect base, plate 3, fig. 1, we shall find that a perpendicular elevation must ensue; and the figure that is seen in plate 4, fig. 1, will be produced, the base giving angles of 60° and 120°, and the elevation angles of 90°: the smallest division of this will be the *simple prism.*

In examining the *third* compound, consisting of three proportions of one element to one of another, we shall find that, though the base assumed will be the same as in the last, the elevation will be very different; for, consistent with the foregoing laws, a black sphere (for instance) cannot rest any where perpendicularly on a white, without

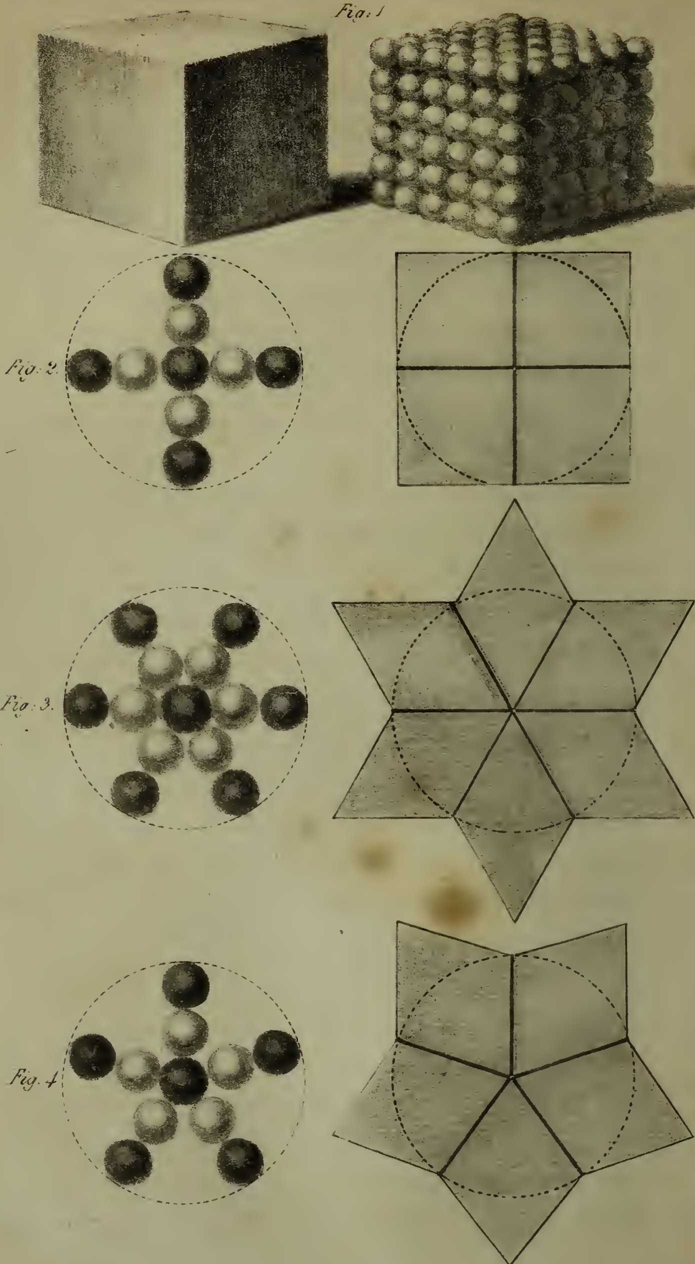
being nearer to one of the same kind than is consistent with equal distribution, but must rest on a *space*, which arrangement will compel an elevation inclined towards the perpendicular, and produce the acute rhomboid; the smallest division of which gives the *tetraedron*, see plate 3, fig. 3.

Thus we find that the same base does not necessarily suppose the same elevation; and, in fact, as we proceed in the examination of the manner in which our principle acts relative to various other compounds, every step will satisfy us of the correctness of the hypothesis.

My limits (which I have already, I fear, transgressed) forbid me to go much further into this examination at present; but the laws which I have laid down are so simple, and at the same time so comprehensive, that any one acquainted with the subject is capable of examining their validity in any case to which he may choose to apply them. I will, however, refer to one or two other applications of them which give very remarkable results, as it solves many difficulties which have presented themselves to a complete and satisfactory theory of crystallization.

In the foregoing instances, as seen in the diagrams, plate 2, fig. 2, a sphere of one kind has been surrounded by *four* of another kind, or *six*, plate 3, fig. 1; but when the compound unites

Plate 4.



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elements whose proportions are indicated by *odd* numbers, such as seven to five, five to three, three to two, &c., one sphere will be surrounded by *five*, and the resulting figure will be one of those called *obtuse rhomboids.*

When the central sphere is compelled to be surrounded by five others, the base must assume angles of 72° and 108° ; and the various elevations on this base, which are influenced by certain compounds, give the various angles of obtuse rhomboids which are found in natural crystals to the fraction of a minute, such as the angles of calarous spar, 105° 5″, and 74° 55″; the angles of iron spar, 73° and 107°, &c. &c.

Again,—if the central sphere is surrounded by *four,* as we have shewn must take place in combinations of two elements in the proportions of one to one, there must be *four radii*, as seen in plate 4, fig. 2, and the angles which such a combination or crystal would assume externally, or cleave or separate in when struck or broken, would be 90°.

When the central sphere is surrounded by *six* others, as shewn above, there must be *six radii*, and, consequently, the angles would be 60°, see plate 4, fig. 3; but when the central sphere is surrounded by *five*, there will be but *five radii*, and the angles will be 72°, which gives the base just adverted to, see plate 4, fig. 4.

It is rather a curious circumstance, and one of some interest, when considered in connection with this subject, so far as it seems to shew a singular effect produced in some respects, and perhaps, if perfectly understood, in all respects, by the same cause; and which, I conceive, somewhat tends to confirm the principle of my theory. I will state the fact I allude to, and leave the application of it to your own judgment.

When a glass half full of water is agitated so as to produce its natural or fundamental tone,* when the vibrations are the most simple, *viz.* in equal proportions, *four* points in the circle or rim will become vibrated, and consequently *four radii* will be distinctly seen on the surface of the water. See plate 5, fig. 1.

When the fifth from the natural tone is produced on the same glass (viz. two to one) there will be *six* points of vibrations, and *six radii*. See plate 5, fig. 1.

But when the vibrations combine in *odd* numbers, they give *five radii*, and, consequently, angles of 72°. See plate 5, fig. 3.

One observation more I would make, for the consideration of those who are disposed to pursue this interesting subject further. It will be observed

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* See page 96, Lecture IV.

Fig: 1

Fig: 2

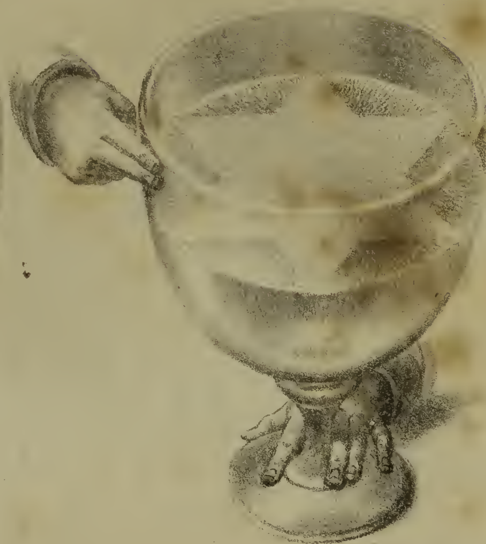

Fig. 3.

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by inspection of the diagrams, that when one sphere is surrounded by *six* others of equal diameters, that the whole must be placed in *close contact* with each other, and the circle completed of a given and perfect circumference; but when *four* spheres only form this circle, that *spaces* equal to one-half their diameters are left between them, and when this circle is formed of *five*, that spaces equal to one-fifth their diameters are left between them. Now in some compounds these five spheres are *compelled* not only to form a circle, but to be in *close contact*; in this case the circumference is considerably lessened, and although the base of the figure is the same, the elevation will give certain angles of rhombs, pentagons, &c. which cannot be formed by any other means.

Many circumstances and analogies in natural phenomena contribute to confirm the theory I have laid before you this evening, but which our time will not now allow us to notice. It will appear, however, I trust satisfactory to you, from what I have previously stated, that all crystals are compelled to assume certain definite forms and appearances, in virtue of the power of certain laws, acting on *one simple* and primitive *figure*, of which figure we have stated all the atoms of matter to consist. And furthermore, that the resulting effects are consistent with natural productions.

As it will be observed by the majority of my

audience, that I have carried my demonstrations no further than regards the *primary* union of atoms with each other, or combinations of *two* elements, I must therefore beg to observe, before I close this lecture, that the laws I have advanced equally govern the *secondary* combinations of these primary *compounds*, when even these bodies consist of *three* or more substances. Here a wide field for inquiry presents itself; and if we study the subject, I have little doubt on my own mind, that as the same laws must exist, and exert themselves in the regulation of *all combinations*, a variety of highly interesting effects will hereafter be satisfactorily explained, connected with general as well as with chemical science, the causes of which have hitherto baffled the most ingenious inquiry.

I will state here my opinion, that in all *secondary* combinations of bodies, when that combination is a *definite one*, the substances which are combined in, and constitute the *proximate* body, are in every case *decomposed* or the elements separated from each other, and that they unite in the new compound with the elements of the other body, agreeable to the previous laws and regulations, so that the atoms of each element are compelled to maintain equal distances from each other in the secondary compound, and must of necessity suffer an alteration with respect to their *proximate* positions before this union can possibly take place;

otherwise no balance of power can be effected, or can their *visible* or peculiar characters be altered.

To explain myself more intelligibly, we will suppose that two compound bodies enter into chemical combination with each other—say an acid and an alkali—nitric acid and potassa. Nitric acid is composed, according to our present view of it, of two elements, nitrogen and oxygen; the potassa is also composed of two elements, potassium and oxygen: we have here *three* elements—namely, nitrogen, potassium, and oxygen, combining together in different proportions, forming nitre. Now I believe in this union not only that the atoms of nitrogen, but those of potassium and oxygen, are placed at regular distances from each other, and that they are equally distributed throughout the compound; that they form new positions with respect to each other; and that both the acid and the alkali are individually *decomposed*, in order to form this new combination: consequently, their peculiar characters must be entirely changed, and therefore no property, either of an acid or an alkali, can possibly be discovered while they remain thus combined.

When, however, the elements of this compound are again disturbed by the power of other affinities, each atom seizes its previous partner, and the *proximate* bodies appear again in their original state. Thus by chemical powers, not only the nitric acid

may be made to re-appear, but also the potassa, and these in their purest forms.

I have stated, that when compound bodies combine together in *definite proportions*, I believe these bodies have their elements individually separated, and placed in new positions. I must here state, that when bodies combine in *all proportions*, like sugar and water, spirit and water, &c. I believe the elements of the proximate compounds are *not decomposed* or separated, but that the bodies remain in their original state, and that the compounds are simply *mixed*, each body retaining its elements in their natural positions, and consequently retaining their peculiar properties.

LECTURE IV.

CHEMICAL, OR ELECTIVE AFFINITY, &c.

The subject to be treated of in the present Lecture is *heterogeneous attraction*; so called because it is a power exerting itself between bodies of *dissimilar* natures. It is, in other words, called *elective affinity*; because it is that power by which bodies are enabled to *elect* or *choose* other bodies with which they will unite, or to leave the body to which they are already united, when another is presented to them, with which they have a stronger disposition to form a union. I propose to examine (1st) the nature of this affinity; (2d) the different external circumstances which influence and modify it; (3d) its various results, as they are displayed in general chemical action.

Elective affinity, like that affinity which produces aggregation or cohesion, acts at *insensible* distances only; but, unlike that, it acts between particles of different natures, and it produces compound bodies, more or less unlike the bodies

which it brings into union. The compounds produced by elective affinity are also of a permanent nature; not to be influenced by any of our mechanical powers, but only to be changed or modified by the force of other chemical affinities. In short, it is this affinity which produces what is called chemical action in general; and the results of which action cannot be changed or destroyed but by itself.

When two bodies enter into chemical combination with each other, it must be inferred that *elective* or *chemical* affinity exists between them; and chemical action is usually more or less violent, in proportion to the strength of this affinity. But the changes which take place in the principles and qualities of bodies, in consequence of this action, cannot be judged of by the same criterion. Many saline substances, in particular, when united together, produce other substances altogether different in quality from either of the uniting substances, while but little chemical action can be observed by the senses; and many other substances, by their union, produce the most violent action, without becoming changed, in a more striking degree, than those which combine almost silently and imperceptibly.

Of experiments to prove the *change of temperature* produced by chemical action, an immense

number might be introduced; but we shall content ourselves with as few as possible, and those easily performed.

Mix together two parts of oil of vitriol (sulphuric acid) and eight of water, and the *temperature* of the mixture will be raised above the boiling point of water. If on the outside of the vessel in which they are mixed a piece of phosphorus be attached, it will inflame, simply by the heat produced by the mixture of the two cold liquids within the vessel.

A piece of the metal potassium thrown into water *takes fire*. Mix equal parts of chlorate of potass and camphor together, and touch them with a drop of sulphuric acid, the camphor will *inflame*. The same effect takes place with spirits of wine, or charcoal, instead of camphor.

A mixture of chlorate of potass and sugar forms the instantaneous-light-match, which *takes fire* by introducing it into a small bottle containing sulphuric acid. Oil of vitriol and olive oil produce *great heat* when mixed: oil of turpentine will *take fire* if thrown into nitric acid. Nitrate of copper, if wetted and immediately wrapt up in tin foil, will occasion so much heat that *flame* will be produced, and make its way through the foil.

Intense degrees of *cold* are produced by what are called freezing mixtures.

All these changes of temperature, &c. are pro-

duced in consequence of the chemical action which takes place between the substances which are brought into contact with each other.

Change of colour almost always attends chemical action. Infusion of red cabbage, or the blue infusion of violets, radishes, or almost any vegetable *blue*, will become *red*, by the addition of any one of the common acids. Take a little green vitroil (sulphate of iron) and dissolve it in water, adding to it some infusion of oak bark, or infusion of nutgalls, it will become instantly *black*. To common writing ink add spirits of salts, the black colour will be *destroyed*. To this add some one of the alkalies, say ammonia (spirits of hartshorn,) the black colour will be *reproduced*. Take a *colourless* solution of blue-stone (sulphate of copper), add to it a little spirits of hartshorn, it will become of a beautiful *blue*. To this mixture add some nitric acid, and the blue colour will *disappear*; add another portion of hartshorn, it will become *blue*, as before. Take the *blue* liquid produced by the infusion of red cabbage, and add to it some solution of potass, or soda, or ammonia, it will become *green*. Now add sulphuric acid, drop by drop, it will first become *blue*, and ultimately *red*. Pass the gas called chlorine through the above *blue* infusion, and *all colour* will be destroyed.

Change of taste, and general action on the

human body, may easily be perceived to result from chemical action.

Mix a dilute solution of sulphuric acid, which is intensely *sour*, with magnesia, which has a peculiar *earthy* taste, and Epsom salt will be formed; the taste of which is *neither sour nor earthy*. Phosphorus is *severe* in its action, when taken into the stomach *uncombined;* but the "tasteless salts," as they are called, on the contrary, are exceedingly *mild* in their effects; they are a chemical combination of phosphorus with oxygen and soda.

That *change of outward form* is produced by chemical action, need not be expressly shewn, since it is apparent in almost every experiment we perform.

Chemical affinity is more powerfully exerted between some substances than it is between others; and the laws which regulate this are so important, that no one can be a chemist without knowing, in a great measure, the various bearings of them; that is to say, the various habitudes or affinities inherent in the various substances which come under his notice, and what relative proportion these affinities bear to each other. In fact, it is the exercise of this law which produces all chemical changes, all compositions, decompositions, &c. and the knowledge of its relative action, that constitutes the science of chemistry. But as it is impossible for any one to recollect every relative affinity

which is peculiar to a body, in order to shew these affinities at one view, tables have been constructed, which are of great use in assisting the memory, and as subjects of reference in the laboratory. They are called "tables of affinities:" the substance, the relative affinity of which is desired to be known, is placed at the head of a column; and the substances for which it has an affinity follow in their relative order.

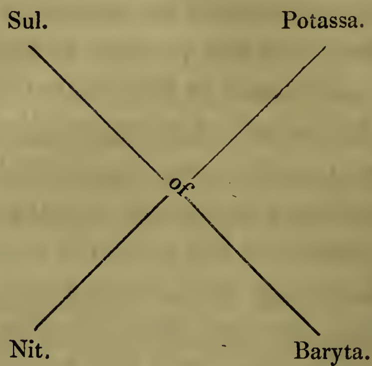
Chemical affinity is either *simple*, as when any one body detaches another from its previous combination with a third; or *complex*, as when two bodies separate two others reciprocally, forming two new compounds. "It frequently happens that the compound of two principles cannot be destroyed either by a third or a fourth, separately applied; but if the third and fourth be combined, and placed in contact with the former compound, a decomposition, or a change of principles, will ensue. Thus, when lime-water is added to a solution of the sulphate of soda, no decomposition happens, because the sulphuric acid attracts soda more strongly than it attracts lime. If the muriatic acid be applied to the same compound, still its principles remain undisturbed, because the sulphuric acid attracts soda more strongly than the muriatic. But if the lime and muriatic acid, previously combined, be mixed with the sulphate of soda, a double decomposition is effected. The

lime, quitting the muriatic acid, unites with the sulphuric, and the soda, being separated from the sulphuric, combines with the muriatic."

If sulphuric acid and potassa be united chemically, they will remain in that union until we separate them by the aid of stronger chemical affinities. This may be done by presenting to the compound, nitrate of baryta: on the addition of this latter compound, the sulphuric acid will leave the potassa, and go over to the baryta, in consequence of the greater affinity of these two substances for each other, than that existing between the sulphuric acid and the potassa. The elements in this case form new arrangements. The sulphate of potassa no longer exists; but a new compound is formed by the union of baryta and sulphuric acid, and a second new compound is formed by the union of the nitric acid and potassa, which, by the first play of affinities, were discarded from their previous union with sulphuric acid and baryta.

We have now formed a sulphate of baryta and a nitrate of potassa, two new compounds; and this change is said to be effected by *compound or complex affinity*. Provided baryta alone had been added to the sulphate of potassa, a *single* decomposition would have ensued; a sulphate of baryta would have been formed, and the potassa, consequently, merely liberated. These kind of changes are

conveniently represented by diagrams The above changes may thus be shown:



The compounds, as first mixed, are represented on the upper and lower extremities of the lines; the change produced is shown by the cross lines themselves. Many other contrivances of this kind are used; but none better than the above.

We have next to notice the various external circumstances which influence and modify chemical affinity, and which consequently in some degree change the apparent regularity of its results. These circumstances are (1) *cohesion*, (2) *mechanical pressure*, (3) *quantity*, (4) *elasticity*, (5) *insolubility*, (6) *temperature*, and (7) *the electrical state of bodies*.

The manner in which *cohesion* affects chemical affinities was considered in a previous lecture.

It may readily be conceived that the effects of *mechanical pressure* or chemical affinity, result from

its bringing the particles of bodies into closer contact with each other than they would otherwise be. These effects are chiefly observable in aeriform fluids, when combinations are performed under circumstances in which, but for the mechanical pressure, they would be disunited; and also in the phenomena of detonation, which, in solid bodies, never takes place without mechanical pressure.

Take a few grains of fulminating silver, or fulminating mercury, and placing it on an anvil, give it a smart blow with a flat hammer; it will explode with violence. So will almost all the substances known by the name of detonating, or fulminating compounds. Rub *lightly* in a mortar three grains of chlorate of potass and about two of sulphur, until they become intimately mixed. Now press *strongly*, and continue rubbing, and a series of detonations will take place. Press *strongly* a small piece of phosphorus on chlorate of potass in a mortar; a most violent detonation will take place. It is prudent in this case *never* to exceed one *grain* of *phosphorus*, and to cover the mortar with a cloth; as otherwise the ignited phosphorus may be thrown out with great force, and occasion mischief. If any detonating powder be folded in paper, and struck on an anvil, the explosion will be louder, and the experiment more safe.

Mechanical pressure will cause carbonic acid gas to unite with water. It will also combine the two gases oxygen and hydrogen, so as to form water.

Mechanical pressure is, in fact, of the greatest importance to chemical research, although it has hitherto been almost entirely disregarded. We shall consider it at some length hereafter.

Quantity also affects chemical affinity in a very observable degree; for it is found that an increase of the quantity of a substance will in some cases counteract an opposing affinity which had previously been too strong for it.

Elasticity also influences affinity, on the same principle that mechanical pressure does, though in a contrary direction; namely, by forcing the particles of bodies to a greater or less distance from the influence of each other's affinities, and thus modifying or altogether counteracting their effects. This is peculiarly the case with gases or airs, which are essentially elastic bodies. The component atoms of several of the gases have a strong affinity for each other, and also for various other bodies; but they will not combine unless mechanical pressure is made to counteract the effects of *elasticity*, and they are thus again brought within the sphere of each other's action. It is found also, that if a body which has an affinity for another body be presented to that other under the two

separate forms of a liquid and a gas, that other will unite with the liquid and leave the gas untouched.

Insolubility influences affinity, in as much as it is also a modification, or in fact a result, of the attraction of cohesion. And this quality of bodies sometimes produces effects, which, if they could not be accounted for on mechanical principles, would go near to overturn many of our most certain and satisfactory theories, as to the relative chemical affinity of certain bodies to others. For example, according to the tables of affinity, it appears that baryta has a stronger affinity for sulphuric acid than soda has; and yet if to sulphate of soda in solution we add baryta, the sulphuric acid is not wholly disengaged from the soda, because the sulphate of baryta, which is partially formed, being insoluble, cannot exert all its force to the best advantage, while the sulphate of soda is soluble; and thus, the favourable circumstances under which it is enabled to exert itself, it gains more than an equivalent for its weaker affinity.

Temperature is another circumstance which influences the action of chemical affinity; and this influence is exerted in various ways, both in favour of, and opposed to, that action. In some cases it promotes the action of affinity, by diminishing or destroying cohesion; in others it opposes chemical action, by causing or increasing

elasticity, which has previously been described as unfavourable to the action of affinity. The effect of *heat* or *temperature* on chemical action, will be examined at greater length in a subsequent lecture.

Finally, the *electrical state* of bodies has a very striking connection with their chemical affinities.

But this is a part of our subject which must be considered separately, and at a future period, when we shall have made some steps farther in advance.

In the chemical union which takes place between various bodies it is observable that they unite with each other in various proportions; but that the same bodies, or bodies of a similar composition, invariably unite with each other in the same proportion at one time as at another. In other words, it is invariably found that certain compounds contain exactly the same relative proportions of their component parts. The theory which has been endeavoured to be established on the facts of this kind, which have already been observed, is called the *atomic theory*, or theory of *definite proportions.*

The student will find this part of our subject fraught with the highest interest, and developing the most curious and beautiful views of the ultimate laws of inorganic matter.

The laws of *definite proportions* are most obviously seen to act in the union of gaseous bodies.

Some will unite in only one proportion—others in various proportions; but whenever bodies unite in more than one proportion, it is invariably found that the second proportion, the third, &c. *are simple multiples* of the first. Oxygen and hydrogen, for example, will unite in one proportion to constitute water. The proportions in which these substances unite, is $11\frac{1}{2}$ of the latter, by weight, to $88\frac{1}{2}$ of the former; or in other words, the oxygen bears a proportion $7\frac{1}{2}$ to 1 of the hydrogen. This proportion, you are to observe, refers to weight alone. In point of volume, the disproportion is, in these particular bodies, on the other side, two volumes of hydrogen uniting itself to one of oxygen; because oxygen is, in common language, fifteen times heavier than hydrogen. Perhaps a more clear and satisfactory explanation of this may be given by stating, that in compositions, consisting of *one* proportion only, it is supposed that every single atom of an element A. unites itself to a single atom of an element B., and that the difference of proportion results from the difference in the relative weights of these atoms. Thus the number 1 being given to represent the weight of an atom of hydrogen, $7\frac{1}{2}$ will be the relative weight of an atom of oxygen. The combinations of two elements in *one* proportion, are called *binary*: where they combine in *two* proportions, they are called *ternary;* in three, *quaternary*, &c.

Oxygen and carbon combine in two proportions only; 100 parts of carbon uniting with $132\frac{1}{2}$ of oxygen, or with 265, which is a simple multiple of $132\frac{1}{2}$. But these substances will unite in *none* of the *intermediate proportions*—nor in none beyond the one stated. Again,—the metal called manganese will unite with *four* different proportions of oxygen; 100 parts of the metal taking up either 14 parts of oxygen, or 28 parts, or 42 parts, or 56; but in *no other proportions.* And you will observe, that the numbers which follow 14 in this statement, are the products of that number multiplied by 2, 3, and 4. Demonstrated examples of this kind have now become so numerous, that the law of simple multiples is generally adopted, with regard to all those compounds which are observed to combine in fixed proportions only. But there are other bodies which combine in all possible proportions, up to a certain point; and there they refuse to combine further. Thus water will combine with any given portion of common salt, up to a certain point; and then it ceases to unite with more. This point has been called the point of *saturation;* and, on examination, it will be found that, at this point, the water has always united with a relative weight of the salt. Other bodies, again, will unite with any quantity of another body, in any proportion,—as alcohol and water, or sulphuric acid and water, &c. But

it is observable, that in these latter instances the union is not between the ultimate atoms of the bodies, but merely between secondary combinations of them; so that these examples must not be considered as militating against the universality of the laws of definite proportions.

The theory of definite proportions, or the definite combination of ultimate atoms in fixed numbers, with respect to the elements which unite together, is now established on so firm a basis, that there are few to be found who doubt the truth of it; and the further we inquire respecting this arrangement, the more we become satisfied, that not only definite combination does exist, but that in virtue of this definite combination, all the harmony of nature is produced, and even the most abstruse and difficult problems may be solved by examining them with a view to these laws. In fact, the same cause which I have presumed to govern and produce the unerring forms of *crystals*, must also produce *definite* combinations of the atoms of matter.

I fear that it will be felt tedious if I here go into this subject minutely, so as to demonstrate, that definite proportion is an *effect* of the same cause as that which governs crystallization: nor is it necessary for me to take up your time to do so, since any one can convince himself of the truth of these results, if he examines the

effect of the operation of this law on a simple *mixture* of elements, in *indefinite proportions*, without order or arrangement amongst themselves; for, presuming our other positions are correct, relative to the ultimate atoms of matter, it will be obvious that they can chemically combine only in definite numbers with respect to each other, and that every indefinite atom must be thrown out, and be incapable of combination. So that, perhaps, it would be more correct if I state, that "definite proportion" is the *primary* effect of this law, and that crystallization is nothing more than a modification, or a necessary result of the same.

But this unerring and harmonious effect, which we call definite proportion, is not the only result of those laws. For my own part, I believe their influence in some way or other governs the effect of all matter, and may be easily traced and demonstrated in many more branches of science than it has been hitherto considered to affect. Musical chords, for instance, or combinations of tone, on which the delightful harmony of music depends, seem to me to result entirely from the same laws as those which govern definite proportions; for as the combinations of chemistry are governed by definite proportions of *atoms*, so the combinations of sound are governed by definite proportions of *vibrations*. As the external *forms* of crystals are produced by certain definite positions and distances between their

component atoms, so the *sounds* resulting from the motion of certain bodies are dependent on definite positions of the particles effected by the machanical stretchings, lengths, distances, &c. of sonorous substances.

Elements in chemistry combine in the proportions of one to one, one to two, one to three, &c. constituting *perfect compounds;* so, also, musical vibrations combine in the proportions of one to one, one to two, one to three, &c. constituting *perfect chords* or concords. Substances in chemistry combine in the proportions of three to two, five to three, &c. constituting *less* intimately formed *compounds;* so it is, also, in regard to vibrations of sound; they combine three to two, five to three, &c. constituting thirds, great sixths, &c. which are *less* perfect *chords;* and so on through the various gradations of harmony of tone.

We have here an obvious and most striking analogy between the laws which govern each of these compounds; for the latter may fairly be considered as *compounds*, though it is but of spaces, or vacuums, that they consist. For tone is produced by a series of detonations, and detonations are produced by the sudden formation and filling of a series of vacuums. One is formed by definite proportions of *atoms*, and the other by definite proportions of *vacuums.* In the one case, we have a certain number of *spheres* producing a harmony

of form, and appealing to the eye; and in the other, a certain number of *spaces* producing a harmony of sound, and appealing to the ear; and in neither case could that *harmony* be produced by any other law, than one which produces a definite or regular and fixed number of the component. An *indefinite* number of elements *mixing* together, would and do produce, not regularity, but confusion; and an *indefinite* number of vibrations or spaces *mixing* together, produce not harmony, but *discord.* That the former is the case I have shewn, and shall have occasion to shew again hereafter. That the latter is the case, I could prove to a demonstration by various experiments, if this were a fit occasion to do so. It may still, however, not be considered as impertinently out of place, if I call your attention in illustration of what I have now advanced to the laws which govern the monochord, the definite division of the organ-pipe, the laws which govern the concords on the French horn, the Eolian harp, &c. &c.

In all those cases certain divisions of the strings, pipes, &c., under the same circumstances, will produce a certain number of vibrations, detonations, or intervals in a given time. These vibrations will either combine or not with other vibrations, as they may happen to be definite numbers with respect to each other. The following experiment may be made. Take a long string and

stretch it against a wall: now slightly put it in motion, and it will be seen by the naked eye, that the first or whole vibration of the string will in a very short time be subdivided into a number of definite lengths, which will be seen in active motion, as well as certain points which will be perfectly quiescent. If those points which constitute the several terminations of the vibrating portions of the string be now marked off, and correctly measured, they will be found to be simple multiples of each other. These lengths, or portions of the string, vibrate in certain definite times with respect to each other, and consequently when tone is produced perfect chords are formed. Thus it is with the string of an Æolian harp: in this case when the string is struck by the wind, it vibrates in certain portions or lengths of the whole, all of which produce certain notes, and which are invariably found to be chords of each other. If the string is long enough to admit it, its tension not too great and the wind favourable, thirds, fifths, octaves, &c. are all given out from the same string.

In the foregoing experiment, and also in examining the division of the monachord, it will be seen that definite lengths of string under the same circumstances produce a definite number of vibrations, in virtue of which combination is effected.

The same cause will also produce definite divi-

sion, and consequently definite vibrations from *circular* bodies. That this is the case may be proved by the following very singular facts and experiments, which I accidentally discovered a few nights since, whilst inquiring into the nature of a very different subject, and proves the connection between these subjects, when viewed in the light of analagous cause and effect.

Take a large goblet (the larger the better), and having filled it two-thirds with water, produce a tone from it, by rubbing the hand previously wetted (or a rosined bow) on the outside of the rim, in the manner the musical glasses are played; with this difference, that you confine the friction as much as possible to *one* point until the tone is produced. *Four* points only of the circle of the glass will become agitated, and these of *equal distances* from each other; which points may be distinctly seen by observing the rimpling they make on the surface of the water. See plate 5, fig. 1. If the tone or note be now raised to a fifth from the first, which may easily be done after a little practice, *six* points in the sides of the glass will become agitated, indicating that six portions of the circle are in motion: see plate 5, fig. 2. If now you raise the tone to the octave, *eight* points of agitation will be distinctly seen.

A large bell-glass, supported steadily on a foot, is more easily made to produce these different

tones by the wet hand than a common goblet, and the rimpling on the surface of the water will be more defined and distinct.

To make the experiment more striking, suspend by threads, from a ring placed over the glass, and equal to it in diameter, eight balls of cork, painted alternately white and black, and placed *equidistant* from each other, resting *lightly* on the inside of the rim of the glass. When the glass is agitated on a point where one of the white balls rests, it will be seen that all the black ones will become agitated, start forward, and cross each other in straight lines, while every white ball will remain at rest. This proves that those portions of the glass on which the black balls rest, are violently agitated, while those on which the white ones fall are not at all affected. These points, it has before been observed, are definite divisions of the circle of the glass, and alternate with respect to each other. Suspend a number of small balls of cork all round the rim of the glass in the same manner as the last, and the points of vibration will be seen by the agitation of the balls at certain points only. Thus four may be seen, as in the last experiment, and when the fifth note is produced, six, &c. &c.

Musical and chemical combinations, I feel no doubt in my mind, depend in a great measure on similar, if not on the same regulations. Modu-

lation, also, is an imitation of "definite proportion;" for every different note in the scale of music, in respect to time, is a simple, multiple, or divisor of the other.

I have observed the same results to obtain in electrical and magnetical phenomena; and, in fact, I doubt if there is a single branch of science in which its operations may not be traced. At all events, its action is calculated to lead us into new and very important views with respect to chemical science.

Before concluding this lecture, I think it expedient to allude to the New Chemical Nomenclature which has of late years been generally adopted in the scientific world. This admirable and beautiful invention was first introduced by Lavoisier, and a society of French chemists: and it has unquestionably been of the utmost importance to the progress of the science, not only by facilitating the inquiries of those philosophers who were at that time engaged in chemical research in different parts of Europe, and by making the results of their several inquiries available to each other; but it has, no doubt, caused numerous other persons to engage in similar inquiries, who, but for the facilities thus afforded, would have been deterred from commencing them.

The beauty and utility of the new Nomenclature consists in its perfect simplicity, and the ad-

mirable aid which it affords to the memory of the student, by its power of indicating the nature and composition of substances which may never have been examined, or even heard of before. When any new compound is discovered in chemistry (and these discoveries are making daily), it is the practice among chemists to give the new substance such a name as shall necessarily indicate not only the elements, but in many cases the *proportions* of those elements of which it consists. It would occupy too much time if we were to go much into detail in explanation of the manner in which this is effected: but we will endeavour, in a few words, to make you acquainted with the *principle* of it. Under the general name of *salts* there are probably not less than fifteen hundred differently composed substances, all of which it is important, and even necessary, for the chemist to be acquainted with the composition of. Now, to *recollect* all these compositions, by an effort of the memory, would be absolutely impossible, supposing their names to be arbitrary; but, by means of the new Nomenclature, the chemist is enabled to determine this composition accurately, the moment he hears the name of any one of all the compositions in question. This important advantage is effected by giving to each salt a name which shall, by some one syllable of it, express not only each of the elements which exist in it,

but the relative proportions in which they are combined: the commencement of the name always indicating the acid, and the proportion of that acid, and the close indicating the earth, alkali, or metal with which the acid has combined: for all salts consist of an acid joined in a certain definite proportion to one or other of those substances. Thus, if I had not previously been acquainted with the composition of *muriate of soda,* I should at once learn, from its name, that it consists of *muriatic acid,* joined to the alkali called *soda—muriate* of *soda.* It is the same with all the others. The name of *sulphate of lime* at once teaches me that the substance to which it is applied consists of sulphuric acid and lime.

With respect to the manner in which the name is made to indicate the *proportion* of acid which exists in the salt, this is effected by changing the *termination* of the first part of the name: thus the lesser proportion of oxygen contained in a salt is indicated by the termination *ite,* and the greater by *ate;* and when there exists a third proportion of acid (as there does in some cases), it is indicated by another syllable being *prefixed* to that part of the name which describes the acid.

The inquiries we have hitherto prosecuted relative to the chemical affinities which produce composition and decomposition, thus reducing bodies to their elementary forms, or creating them from

those forms, naturally lead us to the consideration of those elements themselves.

These considerations will be taken up in our next Lecture, which will be devoted to heat, and its various powers, qualities, and effects.

LECTURE V.

CALORIC.

On placing any part of the human body in contact with the various objects around us, we experience a peculiar set of *sensations*, which result from the relative temperature of those objects as compared with that of the body touching them. These sensations we call either *heat* or *cold*, according as the object we touch happens to be at a temperature higher or lower than that part of our body with which we touch it. If we place one of our hands in a basin of *hot* water, and the other in a basin of *cold*, and then immerse both of them into another basin containing luke-warm water, we shall feel the same water to be cold to one hand and warm to the other.

Caloric is the term used to designate that peculiar matter (supposing it to *be* matter) which causes these changes of temperature, and the sensations consequent upon them. I call caloric *matter*, because, though we are not at present capable of demonstrating it to be such, the prepon-

derance of evidence arising from its effects is in favour of this supposition; and because the observed phenomena resulting from its action are, for the most part, capable of being explained on this theory. The chief points of view in which caloric is to be regarded with reference to chemical science, are its powers as an antagonist to the attraction of cohesion, and as an ally to the repulsive force which, in certain cases, exists in matter. And perhaps this latter view of it should be considered as no more than a modification of the former, since, in point of fact, it destroys cohesion, in virtue of its power of causing or increasing repulsion. Caloric is the most universally diffused of all bodies with which we are acquainted: indeed, as far as our present knowledge enables us to determine, caloric is a necessary constituent of all compound bodies without exception.

With respect to the other elementary substances, we may conceive them to exist absent from or uncombined with caloric; but we cannot detect them in that state, though we may readily trace their effects.

Before proceeding to investigate this substance more in detail, it will be well to state a few of the most remarkable facts or axioms which may be collected together respecting the general laws of its action, premising, however, that it is found to exist in two different states: namely, in a state of

freedom, and capable of being detected by the senses, and of being measured by our instruments; and in a state of dormancy or inactivity.

When in the first of these states, it is called *free caloric*, and in the second it is called *latent*; and it exists in both these states in the same body at the same time. First, then, caloric pervades all known bodies, which is not the case with respect to any other substance whatever. Secondly, the particles are *mutually repellent* of each other, in virtue of which quality they cause or increase repulsion among the particles of all bodies with which they unite. Thirdly, whenever a body changes its state, it invariably either combines with an additional portion of caloric, or it parts with a portion of that previously possessed by it. Fourthly, whenever caloric passes from a latent to a free state, it produces sensible heat; and whenever it passes from a free into a latent state, it produces cold. Fifthly, the presence of latent caloric invariably causes an expansion in bodies in proportion to its quantity. Lastly, free caloric has a tendency to diffuse itself equably over all bodies with which it comes in contact, thus preserving a regular temperature in all.

I have stated that free caloric has a tendency to diffuse itself equably through all bodies with which it comes in contact, so as to preserve an equal degree of temperature in all. This is one

of the most important laws attending its action, and produces most of the common phenomena of what are called *heat* and *cold*. Caloric fulfils this law chiefly by means of a power which it possesses of *radiating*, or being *conducted* from one body to another. Thus, on applying a thermometer (or, as its name indicates, a measurer of heat) to any of the bodies that surround us, we shall find that they all possess the same quantity of free caloric, although on touching them we should not suppose this to be the case. *Iron*, for example, is not colder—or, in other words, it does not possess a less portion of free caloric than *wood*, although to our external senses it seems to do so. The feeling of cold thus produced arises from the action of the above law.

My hand possessing more free caloric than this metal ball which I now hold in it, I at first feel a sensation of cold when I take it up, because the caloric is rapidly passing from my hand into the ball, in order to produce an equality of temperature between the two. If I were to hold the ball till this equality were attained, I should feel no sensation either of cold or warmth. On the contrary, if by artificial means I convey into the same ball a greater portion of caloric than is contained in my hand, and then take it up, I feel a sensation of heat arising from the caloric passing from the ball to my hand, in order to attain the medium

temperature as before: so that cold may be considered as a relative term only; the absence of heat, which it would seem to indicate, not having any known existence in nature.

I have stated that caloric expands all bodies into which it enters: but the *degree* of expansion produced by it is not in exact proportion to the quantity present; for, generally speaking, bodies expand in a greater relative proportion as their temperature rises. Mr. Perkins's new steam-engine is constructed on this principle.

Expansion produced in bodies by heat is general; and the only apparent exception to this law was in *alumina*, which was found to contract even by intense heat. This, however, is now found to arise from the strong affinity it has for water, which cannot be driven off from it but by a very high temperature; and of which, in fact, it will retain a portion, even when submitted to the greatest heat of our furnaces: and almost immediately on its removal into the atmosphere it again absorbs a considerable portion.

We may now regard every substance in nature as being liable to be *expanded* by heat; from the lightest gas, down to the most dense and ponderous solids.

Various and numerous are the experiments by which we may prove this; and our corroborative observations on natural phenomena which daily oc-

cur at once confirm this law, and prove its universal and important action. Hence arises the evening breeze under the Tropics, the delightful zephyrs of our summer days, the shooting of the various tribes of plants and trees, and animation of the torpid and slothlike tribe of certain animals. In fact, heat and light may be regarded as in great measure the rulers of organic life.

The experiments that we shall introduce, connected with this property of heat, are easily performed, but they are at the same time decided in their character. We will commence with showing the expansive effect of heat on *aeriform bodies*, and descend to those which are more *dense* in their composition.

Hold the bulb of an air thermometer over the flame of a lamp until it is very hot, when the *air* it contains will be greatly expanded; insert the end of the tube into water, and as the bulb, which is then perpendicular, cools, and the air it contains becomes condensed, the water will rise in the tube till it almost fills the bulb. If the neck of the tube happens to be very hot (or which is easily effected by holding this part in particular over the lamp), the column of water in the tube will be seen to rise and fall in a very singular and pleasing manner.

This is occasioned by the first portion of water

which touches this very hot part of the tube becoming suddenly expanded and converted into steam, which fills the bulb and forces the water again down the tube; condensation then recommences, and the water rises; if this part continues sufficiently hot, steam will again be formed when it reaches this point, and of course the water in the tube will again fall, and so on alternately rising and falling until this part of the tube becomes too cold to convert water into steam: the water will now first slowly flow into the bulb, there produce a condensation of the air and steam that it contains, thus causing an almost perfect vacuum, in consequence of which the bulb will now be instantly and violently filled with water.

This is a highly pleasing and instructive experiment for the student to perform: he should watch and attend to its various changes.

Take an air thermometer, the larger the better, and insert the open end of the tube into water; apply the heat of a lamp to the bulb, and a considerable portion of the air it contains will be seen to escape and bubble through the water, in consequence of its being rarified or expanded.

Leslie's differential thermometer is a familiar instance of the expansion of air by increase of temperature.

Hold the mouth of an air jar or bell glass over the

flame of spirits of wine: the air it contains will be highly rarified, so that almost a perfect vacuum may be obtained by this means, and which may be made evident in this way: moisten some tow or paper with spirits of wine, and support it on a piece of cork floating on water; set in on fire and place the glass over it as above; the instant the rim of the glass is made to touch the surface of the water, the flame will be extinguished, and the jar will be filled with water almost entirely; showing the degree of expansion previously produced. If a ground jar and transferring plate be used, the experiment succeeds equally well, and various jets may be thus formed. In this latter case the jet tube should be surrounded with paper moistened, or the plate covered with the spirit and inflamed as before. Many of the most pleasing experiments of the air-pump may thus be made, without the use of this expensive instrument.

Cupping in surgery is now performed in this manner, instead of using an exhausting syringe, as was formerly practised.

Liquids expand by heat, but considerably less in proportion than aeriform bodies.

The common spirit and quicksilver thermometers are instances of this property. The pulse glass, as it is called, is another.

The property water has of being converted, or

literally *expanded*, into steam by heat is well known. The steam engine is supplied with mechanical force in virtue of this expansion.

Take the air thermometer bulb and tube, as in the former experiments ; pour in water till it is nearly filled, and then add about two drachms of rectified *sulphuric ether* ; apply the finger to the open end of the tube, to prevent the escape of the liquid, and invert it in a vessel of water. If we now pour *hot* water on the outside of the bulb, at the top, the ether will become expanded into vapour by the heat, and fill the whole of the bulb and tube, driving out the water, and occupying its place.

If we now pour *cold* water on the bulb, the ether will become condensed by the loss of the heat, will reassume its form of a liquid, and the water will again be admitted and fill the tube.

Solids are also expanded by heat; and an instrument called the *pyrometer* has been formed on this principle, for the purpose of measuring the degree of expansion that thus takes place.

This quality of heat in expanding solids, particularlythe metals, is a great disadvantage to the arts in many respects. The greatest is perhaps that of its preventing our time-keepers from preserving their regular rate of going in different temperatures.

I will here relate a great disappointment and loss, as well of time as of attention and care, which once occurred to myself, in consequence of my ignorance of this quality of heat; and I mention the circumstance here, because it strikingly illustrates this property of heat, and eminently proves the necessity of connecting science with the arts.

Some years since, when a very young man, I undertook to build a large organ, and I succeeded even beyond my own expectations, which were yet sanguine enough, for it was admitted on all hands that the instrument I produced was one of a remarkably fine tone. It was built on *theory*, for I had never seen the interior of one till I had finished mine, and knew nothing whatever, practically, of the construction of them. Flushed with this success, I did not see any reason, in *theory*, to prevent my connecting a piano-forte with my organ; on the contrary, I conceived that they would improve each other. I conceived that, by a union, the bad effect of the sudden stop of the organ would be remedied in a great measure by the cadence of the piano-forte, and the mixed tone of the two would produce an effect pleasing and harmonious to the ear. I ultimately succeeded in practice, and combined the two by the same set of keys, and affixed pedals, so as to enable the performer

to play the instruments either separately or together, as might please his fancy. The effect certainly was very delightful, and the expression far exceeded my most sanguine expectations. The instrument being now complete and in fine tone, I invited my friends to witness the effect of it; and after waiting in anxious expectation, I was at last requested to play. I sat down, and, commencing with a fine slow movement, began presently to change my modulation and time into what musicians call an "allegro." Now, then, was the moment to introduce the lively notes of the piano; accordingly I removed my foot from the silent pedal, expecting to enrapture my audience, and receive "showers of applause." But judge of and pity my feelings when I tell you, that instead of a "concord of sweet sounds," my instrument poured forth the most frightful discords that ever fought together for the especial discomfiture of musical ears! You may easily conceive my chagrin and disappointment. The mischief (as you will perhaps have anticipated) was occasioned by this property of heat which we are now considering. The number of persons in the room, added to a better fire, perhaps, than was usual, rose the *temperature*; and, consequently, the metallic strings of the piano were *expanded* by it, their tension became diminished, and of course the notes were all flattened; while

those of the organ pipes were rather affected in the opposite way, so that they produced together a complete separation and discord. The next morning, when the temperature of the room was reduced, the instrument was again in perfect tune.

The *thermometer* is an instrument constructed on the principle of the expansion of bodies by heat; and the temperature of surrounding bodies is measured by the degree of expansion produced by their contact with the mercury, &c. inclosed in the bulb. This is an instrument too well known to need description.

The two most remarkable and important points connected with this part of our inquiry into the nature of caloric, are 1st. the different quantities of it which different bodies require, in order to raise them a given number of degrees in temperature; and 2dly. the different powers possessed by different bodies of permitting it to move among their particles. The different facts which have been collected, relative to the first of these points, we range under the head of the *specific caloric* of bodies; and the second property is intitled the *conducting power* of bodies. The phrase, *capacity* of bodies for caloric, belongs to another part of our subject, as it relates chiefly to caloric in a latent state, or a state not affecting our senses, or our instruments.

If equal quantities of water and of quicksilver be placed at equal distances from a heated body, the water will, in a given time, acquire a less proportion of sensible caloric than the quicksilver, though, in point of fact, the same quantity will have passed into the one as into the other. The quantity acquired in either of these cases, is termed the *specific caloric* of the body. On the other hand, if we place these same portions of quicksilver and of water in a situation where the temperature of the atmosphere is lower than their own, they will cool, or part with their lately acquired caloric, in different times; and these times will exactly agree with the times they required to gain the said caloric, the body which gained it in the quickest ratio losing it in the same, and *vice versâ.* It may be proper to mention here, that in measuring these different portions of caloric contained in bodies, we do not pretend to determine their absolute portion, but merely (as was before stated) their specific portion—the addition they have obtained to what they possessed before. It is impossible to determine what effect a total absence of caloric would produce on the thermometer. According to certain experiments which have been made by Crawford, Irvine, and others, and the calculations which have been founded on them, it may be conjectured that the real zero,

that is to say, the total absence of caloric, would be at least twelve hundred degrees below the freezing point of water.

Another method of determining the relative proportions of specific caloric contained in different bodies, is by mixing given portions of them together, at given temperatures, and then ascertaining the temperature of the mixture. If the specific caloric of the bodies be the same, the result of the experiment must give the mean temperature of the two. Thus, if we add a pint of water at 100° to a pint of the same liquid at 200°, the temperature of the mixture will be 150°; but if we mix a pint of quicksilver at 100°, with a pint of water at 40°, the resulting temperature will not be the arithmetical mean, or 70°, but 60°: hence we infer, that water contains more specific caloric than quicksilver, in the proportion of three to one, in relation to similar bulks; and, consequently, that their relative capacities for it are in that proportion.

With respect to the *conducting power* of different bodies, experiments on this point bring us acquainted with many interesting results. If I place rods of different metals, of equal lengths and thickness, in a heated medium, I shall find that, on applying the thermometer to the opposite ends of them, each will indicate a different degree of

temperature. Place small pieces of phosphorus on the ends of rods of different metals, of exactly the same length and thickness, apply heat to the opposite ends, by placing them in a frame, on a stand constructed for the purpose, and supporting the stand on a plate of heated iron: the phosphorus will inflame at different times on the ends of the different metals, thus shewing, in a very striking manner, their different powers of conducting heat.

It is the same with woods, liquids, &c. and this power is found to agree in some measure with their different degrees of density, their conducting power being nearly in an inverse ratio to their density: in the different woods this fact is particularly observable. In respect to liquids, it is observable, also, that their power of conducting heat is exerted chiefly in a certain direction, namely, perpendicularly, from below to above; and scarcely at all either in a parallel direction, or from the surface to the lower part. But, perhaps, it would be more correct and philosophical to state, that liquids have scarcely any power at all of conducting heat; for the heating of a liquid is effected, not by the caloric passing from one particle of the liquid to another, but by the heated particle becoming specifically lighter, and consequently changing its place in the mass, and per-

mitting another particle to take its place and receive the caloric, and so on, till all are heated. This may be exemplified under various circumstances. Whereas, if heat be applied at the top of a liquid body, the particles of liquid in immediate contact with the heat will receive it; but these particles being the lightest, still retain their place at the top, and consequently do not permit any others to come in contact with the heating medium, and the whole body retains the same temperature as before.

Take a glass tube filled with water, and hold the middle of it over the flame of a spirit-lamp, in an oblique direction; the water will boil in the upper part of the tube, while that in the lower part will remain perfectly cold: indeed, a piece of ice will not be melted if placed at the bottom, but instantly, if it be permitted to rise to the surface. Inflame æther floating on the surface of water, and let it burn there till all is dissipated; then place your hand, or a thermometer, immediately under the surface, and no heat whatever will be perceived to have descended or entered into the water.

Before quitting this part of our subject, it may be stated that the fitness of different kinds of clothing for their respective purposes, depends entirely on the conducting power of the sub-

stances of which they are composed; and when these different powers come to be ascertained, nothing can be more striking and admirable than those arrangements connected with natural history which are thus pointed out to us. Without going minutely into this subject, I cannot avoid noticing, that of all the substances just referred to, such as hair, wool, silk, feathers, down, &c. that which possesses the strongest power of resisting the passage of heat, is the down which grows on the breast of a water bird called the *Eider duck*, which is peculiar to cold climates. If the breast of this animal, which is constantly exposed to the contact of intensely cold water, were not supplied with this guard, the internal heat which is necessary to its existence, would pass away to colder medium, and the bird must inevitably perish. Nearly the same fact is observable in the young swan, or cygnet. The down growing on the breast of this bird, before it has been accustomed to the water, is one of the worst conductors of heat that we are acquainted with. Air being also a bad conductor of heat, we are enabled to apply a portion of it, so as to prevent the effect of cold to our rooms, by confining it between two casements, or two doors. It is on this principle that double doors and windows are constructed, *viz.* on the non-conducting power of the air confined between the two, not on that of the substances of

which they are composed. Ice-houses are also surrounded by a stratum, or partition of air, on the same principle. In the first case, the stratum of air prevents the passage of the heat from the room; and in the second, it prevents the warm atmosphere from entering and melting the ice. On the same principle, we wrap our bodies in flannel to keep them warm, and we wrap ice in flannel to keep it cold; for the wool of which flannel is manufactured being a bad conductor of heat, prevents it from leaving the object, (whatever it may be,) round which it is wrapped, or from penetrating to that object, from without.

Different colours have also different conducting powers; black conducts it the most readily, white the least so. This fact may probably account for the colour of various animals in the frigid zones. The hares and partridges of Lapland are white; which may be regarded as a benevolent provision of nature, to prevent the abstraction of heat from their bodies by the intense cold of the external air. A simple experiment will prove that coloured bodies conduct heat differently; place pieces of coloured cloth on snow, and observe the depth each sinks in it in a given time.

But the passage of free caloric from one substance to another is not effected by the conducting

power of those substances alone. Its most effectual means of diffusing itself consists in its inherent power of radiating from any body which possesses a greater relative portion of it than is possessed by the surrounding media.

Radiant matter is also susceptible of reflection and refraction. Accordingly, caloric may be reflected and refracted exactly in the same manner, and according to the same laws as light is, but not by the same media. The nature of the surfaces of bodies have also a great effect as to the ratio at which caloric is radiated by them, and consequently, as to the ratio at which it is absorbed; for the one is always found exactly to correspond with the other; that surface which soonest parts with caloric being the readiest in receiving it, and *vice versâ.*

These principles, if judiciously applied, admit of considerable practical application to the economy of daily life.

Before quitting this part of our subject, however, I cannot refrain from noticing one striking confirmation of the law which I stated in the outset; that all bodies, in passing from a liquid to a solid form, give out a portion of caloric. Water in becoming ice, or passing from the liquid to the solid state, under certain circumstances, liberates no less than ten degrees of sensible heat.

If, when our atmosphere is at the temperature

of 22° or lower, a vessel of water be so placed that it can part with its caloric without undergoing mechanical agitation, it will he found that a thermometer placed in it will sink as low as 22°, (that is to say, ten degrees belowing the freezing point), and that the water will still retain its form of a liquid. If, under these circumstances, the water be slightly agitated, a portion of it will immediately assume a solid form, and the thermometer will at this moment rise to 32°, indicating an increase of temperature of ten degrees in the whole mass; and this is, in fact, the temperature which frozen water invariably indicates.

This circumstance, added to another most remarkable fact, that water, unlike all other substances, is of a greater specific gravity when in a liquid than in a solid state, accounts for the lower parts of our rivers and seas never being frozen, which they ought to be, according to all other known analogies.

The particles of water, previously to their assuming the state of a solid, conform to the general law of liquids, increasing in specific gravity as they lose their caloric. If this were not the case, our deep rivers, &c., could never freeze at all on the surface, since liquids are non-conductors of heat, and since the absorption of that matter invariably takes place from that part which is presented to the atmospheric air. On the other hand, if water

in its solid form of ice were, according to all analogy, heavier than when in a liquid state, it would sink to the bottom immediately on freezing, and an accumulation of ice would take place there, which could never afterwards be reduced to water; and consequently, after the first few winters of our world, seas and rivers would have been absolutely unknown to it, eternal masses of ice occupying their place.

It was of the utmost importance to the well-being of our world, that the general law, which would necessarily cause the above state of things, should be made, and therefore such a law was made. But it was of equal importance that the above single exception to that law should exist; and therefore that was made also.

It is in consequence of the action of the above law that situations near deep seas are comparatively warm in winter and cold in summer.

It remains for me to notice the principal external and adventitious circumstance which influences and modifies the action of free caloric: this is atmospheric pressure. Under the common circumstances in which our experiments are made, it is found that the same liquids are invariably converted into aeriform bodies by an addition of the same specific quantity of heat—or, in other words, that they pass into that state immediately on arriving at a certain temperature. It is found, how-

ever, that under the exhausted receiver of an air-pump, or on the tops of very high mountains, this law does not hold good; we therefore conclude that the liquidity of bodies, and their change into vapour, depend in some measure on the pressure caused upon them by the weight of our atmosphere, and numerous inquiries have been prosecuted which prove this to be the fact. Indeed, so uniform is the ratio of the effect of this pressure, that we are enabled to determine the height of elevated spots, merely by ascertaining at what point of temperature certain liquids will boil or pass into vapour on the top of them. Water boils at a temperature of 212° under the common pressure of the atmosphere; but it will boil as low as 90° in vacuo, and the more perfect the vacuum, the lower will be the temperature at which it will boil. Place under a glass, on the plate of an air-pump, a goblet of warm water; when exhaustion is made, it will commence boiling. The same fact may be shewn without the aid of that instrument. Take a Florence flask and half fill it with water, hold it over a lamp until it boils; remove it from the source of heat and cork it up air tight, the water will immediately cease boiling; but if it be now introduced into cold water, it will re-commence boiling violently: this happens in consequence of the steam which fills the space above the surface of the water in

the flask being condensed by its introduction into cold water, and thus forming a vacuum. Hold it again over the lamp or plunge it into boiling water, and all ebullition will cease: thus we have boiling produced by introducing it into cold, and put an end to by introducing it into hot water; which, unless the cause was known, would appear rather singular. In fact, if the cork be air-tight, the water may always be kept in this state, and will always boil at a temperature of 90°.

I now proceed to consider caloric under its *latent* form. If we apply a thermometer first to boiling water, and then to water in a state of vapour or steam, we shall find that they both indicate precisely the same degree of temperature—that is to say, they both possess an equal proportion of free caloric. But if we mix given weights of steam and of boiling water with equal portions of cold water, we shall find that the steam will communicate a much higher temperature than the boiling water will. Now since both these hot substances, before mixture with the colder substance, indicated the presence of the same quantity of free caloric, whence has proceeded that superabundance which is found to exist in that portion of water which has been mixed with the steam? The answer to this question involves the principle of *latent caloric*. In fact, while the water remained in a state of vapour, it was intimately

combined with a certain portion of caloric beyond that which was combined with the boiling water; but which additional portion could not be detected by the thermometer, or by our bodily senses. But when the steam, in coming into contact with the cold water, became condensed and reduced to water again, it parted with that additional portion, as well as the first portion which caused it to boil; and thus a certain portion of caloric becoming free, combined with the object nearest to it—namely, the cold water, and raised its temperature through exactly that number of degrees which had been parted with in passing from the aeriform state. It is this latent caloric which is the cause of bodies existing in the form of vapour or air; and our experiments prove to us, that the quantity of caloric which exists in a latent state in the vapour of water at a temperature of 212°, bears to that of water itself, at the same temperature, no less a proportion than 1100° as compared with 212°: in other words, a given portion of water at the highest temperature it is capable of receiving under common circumstances, contains 212 degrees of caloric, while the same portion of water, when converted into steam or vapour, contains about 1100 degrees; consequently, the latent caloric contained in the vapour of water is about 880 degrees. And this fact is susceptible of actual demonstration, for if equal portions by weight of

steam and water at its boiling point be added to equal portions of cold water, they will raise the temperature in exactly the above proportion, provided the experiment be carefully conducted. It is obvious how important the application of this principle may be made in many of the arts of life; and this will be still more apparent when we proceed to our experiments in illustration of latent caloric. Before doing this, however, I will at once state the remainder of what it seems necessary for me to communicate to you, relative to this part of our subject. It is an invariable law, applying to all liquid bodies, that they boil at a certain fixed point of temperature respectively. Now the act of boiling, as it is called, is simply this: those particles of a heating liquid, which are in most immediate contact with the source of heat, when they arrive at this maximum point of temperature, can no longer remain in the form of a liquid, but become suddenly expanded and assume an aeriform character; and instantly on doing this, being infinitely lighter than the superincumbent fluid, they rush upward through it and escape into the atmosphere. It is this sudden changing from a liquid to an air, and the consequent rushing upward, which causes that particular appearance we call boiling: the body thus changed would remain invisible and retain its aeriform character for ever, unless it were to meet with a lower degree of tem-

perature than that at which it assumed that form; but the instant it does meet with that reduced degree, it becomes condensed and visible again, in the shape of a liquid, as before. And I may add, that a certain reduction of temperature, or abstraction of caloric, is capable of reducing all known bodies without exception to a solid form. Thus caloric is to be regarded as the sole and specific cause of all fluidity, and of all vapour or air; and but for its presence and action, all matter must exist in a solid state, and consequently life itself must be absolutely and necessarily extinct. The degree of enlargement or expansion which bodies undergo when changed from a liquid or solid to an aeriform state, is ascertained to be very great. Water in suffering this change becomes, in common language, about 1,800 times larger than it was as a liquid; that is to say, a given quantity of it by weight will occupy 1,800 times the space it did before its change. This supposes our common atmospherical pressure: but all aeriform fluids being elastic, are capable of being diffused into a larger compass than they occupy under ordinary circumstances, or of being pressed into a smaller; and but for this mechanical confinement or pressure, they would in fact become dissipated altogether. The latent caloric also, which is combined with aeriform fluids, is in exact proportion to their density; the one diminishing as the other in-

creases. Thus, the vapour of water, at a common pressure, contains, as I have before stated, 212 degrees of sensible caloric, and about 880 of latent. But if a given quantity of it be forced into half its natural compass (as it may be), it will afford a proportionate increase of sensible caloric, and a diminution of latent. By means analagous to this, steam may be raised to a temperature almost equal to that of red-hot iron. It is a remarkable fact, too, that liquids themselves may, by means of mechanical pressure, be made to unite with a considerable degree of caloric beyond their natural boiling points. Thus, water may be heated to 400 degrees of Farenheit, without passing into an aeriform state. These qualities of fluids have likewise been made subservient to many important purposes in the arts of daily life. Papin's digestor is constructed on this principle; it enables water to maintain a temperature of about 400° without passing into vapour, and thus communicates to it greater solvent powers than it would otherwise possess. This principle has lately been applied with considerable advantage in extracting vegetable matter.

LECTURE VI.

ELECTRICITY.

We have now to treat of a subject most important and interesting, both in its nature and its results, whether regarded with reference to general science, or merely to chemical research. It is in this latter respect alone that we are at present concerned with it. Yet I cannot help here expressing my firm belief, that if we should ever arrive at an adequate and satisfactory knowledge of the nature of this most extraordinary and giant-like power, it will be through the agency of the chemist that we shall reach that knowledge. It would appear from observation that not a single chemical change takes place among the ultimate particles of matter but what is effected by electricity, under some one or other of its forms and modifications. It is said to be the proximate cause of all attraction, whether of affinity, of cohesion, or of gravitation; and equally the cause of all repulsion: whether of that repulsion which acts at insensible distances between the ultimate atoms of

matter, or that which obtains between visible bodies, whether compound or simple.

I shall only devote my attention to this subject, with a view to apply our present knowledge of its laws in explanation of chemical phenomena; and shall commence by noticing the immediate and obvious effects which are produced on matter in its ordinary state, when electricity is excited or disturbed.

If a piece of glass or sealing-wax be rubbed with a piece of dry flannel, they both become what is called, in the popular language of the science, *electrical*, that is to say, the electrical state in which they previously existed is changed or disturbed; and in consequence of this change, they exhibit certain peculiar phenomena, which are found to be altogether dependent on that state. Each of the above substances, when thus excited, will attract to themselves any light bodies that may be placed within a certain distance of them. But they do this in virtue of their being in certain states of electricity, and not, as might seem, in consequence of each having acquired electrical states of a similar kind; these states are called *positive* and *negative*. The sealing-wax being in one state of electricity, attracts light substances (for example, pith-balls) in order to regain its equilibrium with the surrounding media; and in so doing, it charges these bodies with a portion of its lately

acquired qualities, and thus throws them into a state altogether different from their usual and natural one; consequently they (the pith-balls so charged) will no longer remain in contact, but will repel each other.

On the other hand, the flannel, being in another state of electricity, will attract pith-balls in the same manner as the sealing-wax, and charges them also with electricity, and consequently with new powers and qualities; and they, like the former, will also repel each other. But if we bring these two sets of pith-balls, so charged with portions of different species of electricity, and yet exhibiting similar appearances among themselves, into contact with each other, they will exhibit phenomena altogether dissimilar: for those which are charged with positive electricity will attract, instead of repelling, those charged with negative, and the negative will attract the positive: and when this mutual attraction and repulsion has taken place, each substance will be found to have regained its usual and natural state of electricity, and no more appearance of either attraction or repulsion will take place between them, they having thus mutually balanced each other: therefore when the ordinary state (whatever that state may be) is regained, the objects remain at rest.

It is of course not my intention to enter into

an investigation of electricity generally, however important and interesting such an investigation might be made, it would be obviously out of place here. I shall regard it in its connexion with chemical science; and shall, even in taking this view of it, attend to it as a series of facts alone, without attempting to investigate the ultimate laws of which those facts are the results; as every new step that we are enabled to make in this science, instead of clearing up our views respecting those laws, rather seems to throw new obstacles in the way of our ever arriving at a satisfactory development of them.

The first important fact in connection with chemical science is the following: namely, that all bodies in a similar state of electricity repel each other, and that all bodies in opposite states of electricity attract each other; and in this law (at least in my view of the subject) we find the grand disposing cause of all chemical changes, of all kinds, and exerted in whatever degree; the degree of change effected being probably in proportion to the relative degree of opposite electricity that is excited.

All substances in nature become electrical by *friction*, or even by contact; and substances that put on the evidence of positive electricity when rubbed with one body, will evince the appearances of negative when rubbed with one of a different

nature, so that the vitrious and resinous electricity spoken of by elder electricians appears to have no existence in nature. The appearances spoken of, depend entirely on the substance by which they are exerted. Thus, flannel is positive if rubbed on glass, and negative when rubbed on sealing-wax.

The electrical machine, by which electricity is excited in large quantities, is too well known to need description.

The electricity produced by *contact* is obedient to the same laws as those which direct the electricity produced by friction. The contact of two different metals, for instance, excites electricity in an eminent degree; and their power of exciting it is greatly increased by inducing a rapid change of surface. This may be effected by the action of an acid solution on the surface of the metals employed; by which means they expose fresh particles every instant to be thus acted on. It is necessary always that the solution employed be a good conductor of electricity.

We are now speaking of electricity as excited by the well known arrangement called the *galvanic battery*. It will not be necessary for me to go into the history of galvanism, to describe the instrument, or the circumstances which led to its discovery. From the pile of Volta, and various modifications and constructions of it, down to the present day, continual improvements have been

making in this most powerful instrument, and in fact are now daily making.

The following singular circumstance, however, I must mention here: that plates of from one to two inches square are capable of exciting all the *intensity*, or (so to speak) rapidity of effect that can be produced from electricity by this means; but that an increase of size gives a proportionate increase of *quantity*. For example, a battery of plates, *six feet* square, has been found to be incapable of giving a stronger shock to the human body, or of decomposing more water in a given space of time, than the same number of plates of *one inch* square, although they will produce an intensity of heat, while the small ones will scarcely affect the thermometer: we therefore conclude that *size* gives *quantity*, and *number* gives *intensity*.

The electricity produced by the galvanic battery has been satisfactorily shewn, by the most eminent philosophers, to be identical with that produced by the electrical machine, and to differ only in modification or degree; each being capable of effecting all the phenomena resulting from the other, with regard to kind. In fact, the common electrical machine differs from the galvanic battery, simply from its being defective in physical power, if we may so express ourselves.

The law which was announced in the commencement of this lecture, as resulting from the

facts attendant on the changes in the electrical states of bodies, is capable of explaining a vast variety of natural as well as artificial phenomena, which would otherwise be totally inexplicable. All changes in the chemical states of bodies are found to result, in some way or other, from changes in their relative affinities; and all changes in their relative electrical states will invariably produce corresponding changes in those affinities: from this it may safely be deduced as an almost logical conclusion, that the one produces the other. It seems to follow, too, that there is no conceivable change in matter (chemically speaking) that may not be effected by change of electrical state. We have never yet essentially increased our power of exciting intensity of electrical agency, without producing some chemical change that was before thought impracticable. In short, the power lately acquired (through the means of the galvanic battery) of exciting a till then unknown degree of electrical agency, has totally changed the face of chemistry as a science; and substances which had previously resisted all attempts to decompose them, have now yielded to this most important agent.

Results, till now unknown and unthought of, have been effected simply in consequence of our obtaining the means of exciting an extraordinary degree of electrical action among the particles of

matter. The power of electricity in decomposing bodies, or of separating them into their simple elements, was first pointed out by Sir Anthony Carlisle, in a paper in Nicholson's Journal, on the decomposition of water; and has since been investigated with the most brilliant success by Sir H. Davy.

The means by which this decomposition is effected, is by making the body intended to be acted on, form the connecting point between the two opposite poles of an electrical or galvanic battery; and the laws in virtue of which this decomposition is effected, are those which were announced at the outset of this lecture; namely, that particles in similar electrical states repel each other, while those in opposite states attract each other. Now of every compound body decomposed by electricity, the different elements of that compound must be in opposite states; but when the compound is made the connecting point between the opposite poles of an excited galvanic battery, those poles being themselves more violently excited than the elements forming the body that is placed between them, they separate those elements in virtue of their power of repulsion and attraction; *viz.* they repel those elements that are in the same state with themselves, and *vice versâ.*

In this way, acids may be made to pass

through alkalis, and alkalis through acids, without combining; because they are under the power of stronger polarities in this operation than those they naturally possess between themselves: but substances whose elements are all in the same state of electricity, cannot be separated by this means, because all the elements would be carried to the same pole.

I shall now quit this part of the subject, however important it may be, in order to consider another property of electricity, recently discovered by M. Orsted, which will therefore be more generally interesting; especially as it has opened a new field for inquiry, and promises to be of equal, if not of more importance than that part of the subject that we have just alluded to. The property of electricity that I now refer to, is, that of producing *magnetism* and affecting the magnetic needle. Magnetism is a subject, the nature of which, like that of electricity, has eluded the investigations of the most eminent philosophers; but a new light seems now beginning to dawn, which promises a more extensive and satisfactory view into the cause and nature of them both, than has hitherto been obtained.

That magnetism is nothing more than a modification of electricity, the following experiments seem to demonstrate, and they at the same time develop some most extraordinary and sublime

views respecting the causes of certain natural phenomena.

Make a connexion between the poles of an excited battery, from the two ends of a wire, formed into a spiral coil by binding common bonnet wire closely round a cylinder, or tube, of about an inch in diameter; into this coil introduce a steel bar, or several lengths of small steel wire, laying them lengthways and across the circles of the coil. In a few minutes after the electricity has passed through the spiral wire, and consequently round the bar or lengths of steel wire, the latter will all be found to be strongly magnetized; to have, in fact, become strong *magnets*. The same effect may be produced by passing a charge through this spiral coil from an electrical battery. It is observable, too, that provided the coiling of the wire be made from right to left, the positive pole will be north, and the negative pole south; but if the coiling be reversed, that is to say, be directed from left to right, the poles of the magnets will also be reversed; thus it appears, that the *direction* in which electricity passes round the wires, will decide their poles. But if we bind one-half the coil from right to left, and the other half from left to right, and then introduce a bar of steel the whole length of the coil, and submit it to the action of the battery as before, or pass a charge through it from the electrical machine, it will have two similar poles at

the two ends, and a different one in the centre, where the coil was reversed: thus we shall have produced, a bar with two north poles at the extremities and a south pole in the middle, or two south poles at the ends and a north pole in the middle, according to the direction of the electricity, as noticed above.

From these experiments it appears, that magnetism is a product of electricity; and from magnets having positive and negative poles which repel those of the same kind and attract those of different kinds, similar to other electrified bodies, and from various other striking analogies, there seems little doubt that they are, in fact, identical; or rather, that they stand in the relation of cause and effect.

Further: if a current of electricity be made to pass through a wire, which is stretched in a line with, and immediately over the magnetic needle, by making it the connecting medium between the poles of a battery, the needle will no longer remain in its usual situation, pointing north and south, but will instantly start across the current, and point east and west. This experiment seems to prove, that the natural direction of the needle is governed by an electrical current, which is uniformly passing across it from west to east; since, in whatever direction you pass a stronger artificial current, it will be found to point invari-

ably in an opposite direction to that current. We shall probably take occasion to reconsider and apply this extraordinary fact hereafter.

Again: pass a copper wire several times round a globe or light cylinder, and suspend the whole on a point or hook formed of one end of the wire, so as to allow it a free motion on its axis; at the same time place the other end of the wire so that it may dip into a vessel of quicksilver, allowing it also to move easily. Now, connect the point where the hook rests with one end of the battery, and the quicksilver with the other, so as to induce electricity to pass through the wire and round the globe; hold a magnet within the globe, and it will begin gradually to revolve on its axis, and continue to do so with a steady and uniform motion. Other revolving experiments are highly interesting, for an account of which I must refer you to M. Ampâre's publications.

Another property of electricity is, that whenever the connexion is made between the two poles of a battery, by a *good conductor*, it passes silently and without any visible effect; but if this connexion be broken, and the *current impeded* or disturbed, that heat and light are produced; as when the two ends of the connecting wire has a small stratum of air (which is a bad or imperfect conductor) intercepting its passage: but this is more strikingly evident in a large

battery, when charcoal points are placed at the point of contact; light and heat are then produced in immense quantities. Make a small steel wire part of the circle, by joining it to the positive pole: touch very *lightly*, with this steel wire, a portion of quicksilver that is in connexion with the zinc or negative pole, the wire will burn and scintillate very beautifully at this point; yet no heat whatever will be produced in the substance of the wire. Now plunge it into the body of the quicksilver, and it will instantly become red hot the whole length, and perhaps fuse and run into globes. From this experiment I am disposed to infer, that at the point of union first made on the surface of the quicksilver, the electricity was, annihilated, or by some means totally resolved into light and heat. In the second case, where the wire became red hot, I suppose that it then partially passed through the substance of the wire, although with great difficulty, which occasioned the heat; and that through larger wires it passes without even raising their temperature, because it is not retarded in its progress, or forced to assume a new feature.

I cannot avoid coming to the conclusion, in my own mind, that the regularity, the beauty, and the harmony of all the changes which take place in the material world will, one day or other, be found to depend on the one grand dis-

posing cause of electricity; and, above all, in the animal economy, where these changes are so vitally important, that it seems peculiarly desirable to ascertain in what manner, and to what extent, the foregoing may be safely and judiciously applied.

That the animal structure, and its various functions, are altogether dependent for their healthfulness on certain chemical changes that are perpetually going on, is now universally admitted; and I expect it will not be long before it will be as universally admitted, that these chemical changes are brought about by electrical causes.

I fear it may be considered that I have already travelled out of my appointed course: but still I am unwilling to conclude this lecture without touching on one other point connected with electricity, as influencing the phenomena of animal life. I mean the different states of our mental temperament at different times, or what is in common language called the different states of the animal spirits.

That organic matter has some influence on the mind, cannot for a moment be doubted; and that the stomach is the chief source of this influence seems equally certain. Further, it is well known that a sympathy of the most intimate nature exists between the skin and the stomach. Now, holding, as I do, that all organic changes are, in some

way or other, dependent on electrical agency, and that that agency is mainly available to us by means of the atmosphere, which serves as a conductor of electricity between the clouds to the earth, and the human body; can it be considered as too fanciful a supposition, if I attribute the various changes of state in the human temperament, especially in persons of a nervous and irritable habit of body, to corresponding changes in the electrical state of the surrounding media; such as the earth, the atmosphere, &c.

Animal heat has erroneously been stated to result from respiration, in consequence of the condensation of that air which is received into the lungs. This, however, is found to be a mistaken idea altogether; for in actual experiments made on animals, the lungs have been found to be the coldest part of the body instead of the hottest, which they should be, if animal heat was generated in them. It has from more recent experiments been discovered, that it depends in a great measure on electrical action: in fact, it may be stated that the nervous construction in animals bear strong resemblance to the arrangement in a galvanic battery; and that, after a nerve has been injured, the heat of that part of the body to which it communicates is found to be much below the general standard temperature. Electrical ac-

tion on the animal system is very imperfectly understood, although it acts a very important part in the animal economy, and will, no doubt, hereafter artificially be used with the most beneficial effect in relieving many of the diseases incident to the human body, when its peculiar action becomes more perfectly known: hitherto it has been of little advantage.

I have briefly stated the most interesting phenomena attendant on electrical action when taken in connection with chemical inquiry, without going generally into the subject, because, to have given the necessary experiments, and investigated its nature and peculiar laws in a satisfactory manner, would have required a whole course of lectures, instead of the small portion which I can now devote to it. In connection with our immediate object, however, it would have been impossible for me to have passed it unnoticed, because it is at this time by far the most valuable agent we possess, for decomposing and separating some of the elements of bodies from their combinations, and exposing them in their simple state to our examination, and will every day become more so, in proportion as we improve our means of obtaining and applying it.

We have considered the laws by which elements are combined, and also those by which the chemist

is enabled to reduce them again to their simple state, *viz. chemical affinity, heat, and electricity.* I shall, therefore, in my next lecture attempt to show the action of some of those laws in the phenomena of combustion, and then proceed to notice the simple bodies themselves.

LECTURE VII.

COMBUSTION.

Among the various chemical changes which take place in matter, none are more striking in their appearance, and at the same time more important in their results, than those produced by Combustion. It is at once the most beautiful, as well as the most valuable and efficient agent in the progressive improvements of general science, and, consequently, in the progressive march of refinement and civilization.

In regard to chemical science in particular, as an agent for facilitating the examination of the various compositions of inorganic matter (which examination is the principal province of chemical research), combustion performs an office of which no other known power is capable.

What is in common language called fire (which is the immediate and proximate effect of combustion), was during many ages (and those the wisest of the world) regarded as one of the four elements of which all things were composed; and

fire was, in some of the not least enlightened parts of the world, worshipped as the first great cause, the source, as well as the director of all things. I mention this merely to convey to you some idea of the extent and influence of combustion, as a natural phenomenon, as well as of its infinite importance in the estimation of all mankind, even before its nature had been investigated to any satisfactory practical result.

Until within these fifty years, the nature and theory of combustion was entirely unknown. It is the object of the present lecture to illustrate this theory, as it is universally now received, and to explain and exemplify its most striking effects. That temporary state of matter which we consent to call combustion, I will define to be the active and visible result of a play of certain chemical affinities, which obtain between certain bodies, when brought into contact with each other at a temperature higher than their natural one. I will add that, in order to the existence of combustion, it is indispensable that there be present *two* elementary substances of totally different and opposite natures, the one a *combustible body*, and the other a *supporter of combustion* These bodies are usually classed under the general heads of electro-negative, and electro-positive substances; because they are believed to possess opposite electrical states, and are, when immediately under gal-

vanic influence, invariably attracted to the opposite poles of the galvanic circle. The electro-negative substances, or the supporters of combustion, are oxygen, chlorine, iodine and fluorine; these are attracted to the positive pole. All the remaining simple substances in nature with which we are acquainted, are attracted to the negative pole; they are therefore said to be in a positively electrical state, and are all combustible bodies.

The electro-positive, or combustible substances, are hydrogen, carbon, sulphur, phosphorus, all the metals, and boron. Some of the earths having been proved by Sir H. Davy to be metallic oxides, the remainder of them are now presumed to be such; and I therefore include them among the known metals as combustible bodies. Into these two classes, then, all the elements of matter are now divided.

Proceeding another step into detail, I may state that, during the process of combustion, the elementary body, termed the supporter, is invariably condensed, and combined with the combustible body; and in consequence of this new modification or arrangement of the ultimate particles of matter, or from some change in their electrical states, sensible light and heat are given out; for though similar products to those of combustion may in some cases be obtained by the spontaneous condensation of oxygen, without the evolution of

light and heat, yet the sensible presence of these is necessary before the process can take the name of combustion.

To prove that two different elements are necessary to the existence of combustion, let the following decisive experiments be performed: Fill a bladder with *hydrogen gas*, or with coal gas; having attached to the bladder a stop cock and jet, press the bladder and apply a light to the issuing gas, it will *immediately burn* as it passes into the atmosphere, through the jet: we thus prove it to be highly *inflammable*. Now fill an air jar with the same gas, over the shelf of the pneumatic trough, (taking care that no atmospheric air be mixed with it); plunge into it a lighted taper, or even burning phosphorus, and it will instantly be *extinguished*, proving that although hydrogen is inflammable, it is *incapable of supporting* the flame of the taper, or of phosphorus. The hydrogen will be seen to burn at the mouth of the jar where it is in contact with the atmosphere, and the taper will be re-kindled when brought out through this film, or partition of flame. The other inflammable gases have the same properties in this respect. Fill a bladder with *oxygen*, as in the last experiment, press it as before, and the gas will issue through the jet; but although a lighted taper be presented to it, it will *not inflame*, proving that it is not inflammable. Fill an air jar or receiver with this

gas, and introduce into it a lighted taper, as in the previous experiment with hydrogen, and the taper will burn with increased splendour: introduce ignited phosphorus, and it will burn with so much splendour as scarcely to be borne by the eye: for the purpose of introducing the phosphorus, little copper ladles are used. Introduce a wood match, just visibly red, it will be lighted instantly. These experiments satisfactorily shew that oxygen, although not in itself inflammable, is eminently a supporter of combustion. To prove that an inflammable body will not burn without the presence of a supporter of combustion, introduce a lighted taper into a jar of carbonic acid gas, or of nitrogen gas, and it will instantly be extinguished. Put into a glass of boiling hot water a small piece of phosphorus, it will fall to the bottom of the water and remain there uninflamed, notwithstanding the *temperature* of the water is sufficiently high for its inflammation. This arises entirely from there being no *supporter* present, which may easily be proved by experiment; for if the stem of a tobacco pipe, or other tube, be inserted into the water, so as to reach the phosphorus, and a current of oxygen gas be made to pass through it, the phosphorus will instantly burst into flame under water. Atmospheric air being also a supporter, in virtue of its oxygen, it answers the purpose nearly as well. This experiment shows that

the phosphorus was only prevented from burning when under hot water from want of something to support combustion, and directly proves the necessary presence of two elements for this purpose, and the relation the action of each bears to that of the other.

Combustion is one of those grand operations which are constantly going on within the bowels of our earth, where it serves the important purposes of composing and decomposing an immense variety of substances, necessary to the renovations and revolutions which are perpetually going on among all organic, as well as inorganic matter. It is termed *ignition*, *inflammation*, or *detonation*, according to the comparative intensity and rapidity of its action. Substances at a red-heat are said to be in a state of ignition; inflammation, is used when the burning body produces flame; and lastly, when combustion is instantaneous, it is termed detonation, or explosion.

These different states of combustion, or its different degrees of activity, depend on the quantity of matter in contact, and the facility with which the elements necessary to combustion are disengaged from the mass; and also on the comparative force of their appetite, or affinity for oxygen, and their capacity to receive and unite with it. Moreover, when the affinities that obtain between the compositions of combustible bodies are weak-

ened by the application of a certain portion of heat, and they are thus disengaged from other combinations prior to the addition of that further portion which is necessary to combustion, then the action of combustion is most violent of all. Thus, if the element oxygen (the supporter of combustion), and the element hydrogen (the most combustible of all bodies), are brought into contact with each other, while both are in a state of gas, and inflamed, we have an instance of combustion at its most intense extreme.

The theory of combustion was very little, if at all known prior to the discovery of the composition of our atmosphere. This brilliant discovery of Dr. Priestley (to whom we are indebted for so many valuable additions to chemical as well as general science), afforded a satisfactory explanation of this most interesting and important of all chemical, and perhaps of all natural phenomena. Lavoisier's, or the French theory, as it is termed, may be considered as correct, as far as it goes. It satisfactorily explains all the phenomena of combustion to which I have hitherto alluded: it notices, too, the invariable evolution of light and heat, as an effect of the rapid combination which is formed between the combustible body and the supporter of combustion.

In proceeding to investigate whence this light and heat arise, and by what process they are

evolved, it is said that the heat is liberated from the supporter of combustion, and the light from the combustible body. When very high temperatures are produced, heat is given out from the combustible body also, in consequence of its change of form, and from the condensation which it suffers; for condensation invariably occasions the liberation of heat. It is a universal law of nature, that bodies passing from a rarer to a denser state, give out a portion of heat; in the case of combustion this law is peculiarly striking; and indeed the chief character of combustion altogether depends on it.

When I add, that the *intensity* of combustion is invariably regulated by the rapidity of condensation, perhaps I have said all that is necessary on this part of the subject: I therefore pass on to more general considerations.

I have stated that oxygen is the grand supporter of combustion; under all common circumstances it is the only one. When I add, therefore, that the grand source of this supporter is the common atmosphere we breathe, and that oxygen is as necessary to health and vitality as it is to combustion, it will be obvious that any thing which diminishes the needful proportion of that oxygen, will detract from the healthfulness of our atmosphere. This may be regarded as a trite subject of consideration, but it is nevertheless

one that cannot be too often, or too strongly insisted on : for, to use a remarkable, and in this case an almost unavoidable play of words, it is indeed of vital importance. This induces me to touch for a moment, in passing, on the subject of the common fires used in our sitting-rooms during the winter.

In this case, the sole object of a fire being to warm the room in which it is placed, and its certain effect being to cause what is called a draft of cold air into the room, it is clear that, unless we make our windows and doors air-tight, we ourselves frustrate our own purpose : for a person sitting near a fire in a room into which that fire causes a draft of cold air, may be said to furnish the worst possible example of being " between two fires," as the phrase is. But if, in seeking to avoid this evil, we do make our doors and windows air-tight, we have placed ourselves in a still worse perdicament, like the fish in the fable : for now the fire necessarily consuming the vital air of the atmosphere of our room, and our precautions with respect to the doors and windows having prevented any fresh supply from reaching it from without, not only the air becomes unfit for us to breathe, but our fire goes out for want of food. I am now supposing that we have succeeded in making the room in question air-tight; luckily, however, we cannot do this: but there

can be no doubt whatever that health is injured in the exact proportion that we can do it. It is a demonstrable fact that this must be so. That this state of things should last when obvious remedies for the evil are at hand, is remarkable; yet so it is. If fires were kept on the outside of our rooms, with flues passing from them into the room required to be warmed, or underneath them, so as to convey a stream of warm air into contact with the air of the room, that air would be gradually warmed throughout. In this case our rooms might safely be made air-tight, because the process which heated the air contained in them would in no degree tend to decompose its elements, or to affect its fitness for supporting animal life; and besides, when once the whole of it was thoroughly warmed, it would require very little additional heat in the flue to keep up that warmth, and a great saving in fuel would thus be effected. But I am afraid we must change all our present habits with regard to domestic life, before we shall consent to part with the cheering sight of a sea-coal fire.

All combustible bodies are not capable of entering into sufficiently rapid combination with oxygen to enable them to inflame or burn at the same elevation of temperature. Some substances have so great an affinity for it, that they take fire at a very low temperature; whilst others, on the

contrary, require the highest degree of heat we are capable of producing. The various degrees of heat necessary for the inflammation of combustible bodies, when in a *solid* state, are pretty well understood; but the temperatures at which *gaseous bodies* inflame are not so well known, and appear to me to have been, hitherto, very incorrectly stated; and this error seems to have arisen from the unfavourable manner in which the experiments have been made with a view to ascertain this point. It is stated by some, that hydrogen gas requires a red heat; by others, that a glowing red heat is not sufficient, but that a bright red heat is required: all authorities, however, appear to agree that a temperature of about 1000° is necessary for its inflammation.

Several circumstances which I accidentally observed, while making a series of experiments on a very different subject, convinced me that this high temperature was not at all necessary for the inflammation of hydrogen, and induced me to institute some experiments, in order to ascertain, if possible, the true degree of heat required to enable combustible substances, in the state of gas, to combine with the various supporters of combustion; in other words, to ascertain the precise temperature at which gaseous bodies inflame. On inquiring, as far as my opportunities allowed me, into the various methods employed

by the most distinguished philosophers to ascertain this point, it appeared to me that altogether new means and modes of experiment were necessary before any thing like satisfactory information could be acquired; for the means hitherto employed seemed necessarily to involve much contradictory evidence, and could scarcely be expected to furnish to the operator the same results at different times. For instance, if a red-hot iron be plunged into a jar or receiver filled with hydrogen gas, it is very uncertain whether it will inflame or not: in fact, no certain data can thus be obtained; for, in the first place, we have no means of measuring the real temperature of red hot iron, and are enabled to judge of it only by certain appearances or degrees of redness it assumes, which every one knows must be deceptive as indications of the true temperature. But even supposing that we could be certain that the temperature of the heated body which we thus plunge into combustible gases was always of the same temperature when used for the experiment, the resulting effect would not always be the same; for combustible gases cannot burn without the presence of a supporter, and the quantity, &c. of that supporter could not, in this way, be regulated in all cases alike; and, if it were previously mixed in just and particular proportions, the result would still be uncertain, because the quan-

tity, &c. of the gas immediately operated on, would interfere with the correctness of the experiment.

It has been observed, that if a piece of ignited charcoal, just *visibly red,* were placed on the mouth of a jar containing hydrogen gas, that the gas would not inflame; but that if the charcoal was simply blown on, that the hydrogen gas would then inflame, because it is stated, that the charcoal, or a portion of it, by the current of air thus applied becomes elevated to a *white heat,* at which temperature the gas inflames. So, also, in the case of plunging a red-hot iron into it: unless this redness were a *bright one,* no inflammation would insue. Hence the conclusion, that these temperatures are absolutely necessary for inflammation of hydrogen gas.

I do not conceive this conclusion to be a fair one: and my reasons for thinking so I will submit for your consideration. All gaseous bodies are elastic, and their particles move with the greatest facility amongst themselves; therefore when a heated body (say a bar of red-hot iron) is plunged into it, it appears to me a necessary consequence that the particles in immediate contact with the heating body, become lighter by their comparative increase of temperature, and therefore pass suddenly away into a colder medium, before their temperature is risen to that

heat necessary for their ignition: the particles which thus pass away from the sphere of heating action are instantly succeeded by another set of particles at a lower temperature, which pass away in their turn, from the same cause; and thus there is a perpetual interchange of temperatures, without the adequate one ever being attained. In the above view, we are supposing the heating body to be at a *red-heat* only, such as a mass of heated iron; but if a body at a *white heat* be placed in contact with the inflammable matter in question, the particles of this latter receive the required temperature necessary for their inflammation *suddenly and at once*, before they have time (if I may so express myself) to make their escape.

It is obvious, if my reasoning is correct, that the whole volume of gas under experiment must be heated to a certain temperature, or a portion of it suddenly heated to this particular temperature, before it will inflame. Now this particular point of temperature cannot be ascertained by the above method of experiment, nor do the other methods of experiment hitherto adopted appear to me to be more conclusive or satisfactory; at least those that I am acquainted with.

If, for instance, we heat a portion of hydrogen gas in a porcelain or other tube, say to a temperature of 600°, and, in order that it may inflame, admit a portion of atmospheric air to it, it is

evident that the quantity of atmospheric air necessary for the support of its combustion at common temperature, say 60° or 70°, must instantly rob the hydrogen of a considerable portion of its acquired temperature, and thus sink the whole to perhaps about 200° or 300°.

Again, if we mix the supporter, oxygen, and the combustible body, hydrogen, together, in the proper proportions for combustion, and heat them as before in a tube, they will combine and form water without inflammation, and at a comparative low temperature.

The usual methods, then, of endeavouring to ascertain this question being unsatisfactory, and the question itself being one of considerable importance, I lately instituted a series of experiments, for the purpose of endeavouring to throw some light upon it; some of which I will now detail, leaving it to you to draw the true conclusions resulting from them.

To obviate as much as possible the disadvantages alluded to in the first method of experiment, namely, that of plunging into, or bringing in contact with gaseous bodies, a heated substance, I passed hydrogen gas through melted metal of known temperature, in very small bubbles; the column of the metal through which the gas passed up being fourteen or fifteen inches in height, I conceived that by this means I should give the

gas time in its ascent, to gain the exact temperature of the melted metal. This succeeded in part, and I found that the gas, on arriving at the surface of the metal, inflamed at a much lower temperature than that generally stated, and, which somewhat confirmed the truth of my previous reasoning: I found, that the smaller the bubbles of gas were, the more easily they would inflame. This, however, was not a conclusive experiment, because, in the first place, aeriform bodies are such bad conductors, that it is more than probable the whole globule of gas was not heated thoroughly; and, in the second place, the atmospheric air on the surface was not of the same temperature with the metal. My next attempt was to pass a current of atmospheric air, heated to the temperature of the metal, over its surface, so as to meet the bubbles of hydrogen as they rose, and thus bring both together at the same temperature.

I could not well manage this experiment, or could I correctly measure the temperature of the atmospheric air which was thus heated and forced on the surface, because it mixed in its passage with a portion of cool air, and thus became reduced, yet, from the imperfect results which I obtained, I was convinced of the comparatively low temperature at which this gas will inflame. I now made a uniform current of carburetted hy-

drogen or coal gas to pass through small apertures, similar to a common gas burner, (see plate 6th, (*h*)) by a regular pressure made by a column of quicksilver; I surrounded this with a cylinder of copper (*a*) which occasioned a draft of air from below through it; in its passage through this chimney, the atmospheric air became heated by the flame of the burning gas; on the top, and communicating with this chimney, I placed a globe of copper,(*b*) in which the air became more generally and perfectly heated; out of this globe it passed by an opening in the top(*c*). I now placed a thermometer (*d*) and corresponding index (*e*) perpendicularly over this orifice, on a moveable slide,(*f*) this enabled me to fix it at any given distance; by which means I could read off any temperature it indicated, at any given elevation perpendicularly over the opening in the globe. The thermometer was now fixed at a point which indicated a temperature of 428°; and on this spot I made a small stream of *hydrogen gas* to issue from a small jet,(*g*) and found that it instantly inflamed. It will be evident that at this point the atmospheric air or supporter was heated to a temperature which was correctly indicated by the thermometer to be 428°: the stream of hydrogen, or combustible substance was so small, and the heat so generally diffused, that it

instantly became of the same temperature with the supporter, and consequently inflamed.

The carburetted hydrogen which was burning within the instrument, and supplying heat to the air, both within and above the globe, was made in this case to be always of the same quantity and same force by the pressure of a given column of quicksilver; because in this instrument uniform pressure is absolutely necessary, otherwise the heat and flame would constantly vary, and no true temperature could be read off. In the instrument now represented in the plate, I have made a very different contrivance for regulating uniformity of pressure, and find it from experiment, capable of measuring with the greatest correctness, every possible force of pressure from five grains to a square inch, up to five hundred. It will be described hereafter, as it is the instrument by which I have discovered many other very interesting facts relating to gaseous bodies.

I tested *carburetted hydrogen* gas by the same means as the above, and found the temperature at which it inflamed to be at about 500°. *Solid* bodies may be tested by the same instrument. In order to ascertain the temperature at which they inflame, nothing more is necessary, than to place the smallest morsel of the substance to be examined, on a fine platinum wire, and to hold it at various distances above the opening of the globe,

until the precise point is seen at which it takes fire: the true temperature of this point is then to be measured, by bringing the bulb of the thermometer to the spot. In this manner I found that *solid bodies*, phosphorus, sulphur, camphor, &c. inflamed, and sublimed, at the exact temperatures given by the usual methods; and this circumstance convinced me that the results I gained respecting *gaseous bodies* were substantially correct; or, at all events, that the principle of the instrument was true.

These experiments may be made, although not in so correct a manner, by using a common argand or spirit-lamp, instead of that uniform and steady flame produced by the instrument in question. It will be found by any one who tries the simple experiment, that a stream of hydrogen gas will inflame, over a common lamp, at a point where the *hand may be held without pain* for many seconds; which fact must convince him, that the high temperatures which are usually stated as necessary for this purpose, are altogether incorrect; and that the errors have originated from some inaccuracy in making the experiments, or from not taking into consideration the habitudes, of this form of matter.

As it may be an interesting question, to some at least, why certain gaseous as well as solid bodies burn, or undergo combustion, at

a lower temperatures than others? I will here make a few observations on the subject. The reason appears to me, to depend entirely on the different affinities of different substances, for the various supporters of combustion. Combustion is, in fact, nothing more than a rapid combination and interchange of different elements among themselves; it is no doubt affected, in some measure, by the attraction of aggregation subsisting between the particles of compound bodies; but, generally speaking, it depends on the rapidity, with which the combustible body is capable of *decomposing the atmospheric air*, and combining with its oxygen, in virtue of its greater or less degree of affinity for that body.

Many facts might be stated in corroboration of this opinion: among others the following, which I will, after stating them, endeavour to exhibit to you by experiment.

If oxygen be present uncombined, substances will burn in it at a much lower temperature than they otherwise would, because they have not to overcome the affinity of oxygen for any other body. Thus a taper, as you have before seen, will re-kindle at the temperature of a low red-heat, if plunged into uncombined oxygen; whereas, in atmospheric air, its attraction for that supporter of combustion, is not strong enough to separate it from the nitrogen, with which it is combined.

Again, *phosphuretted hydrogen* will inflame spontaneously at the common temperature of our atmosphere. Phosphorus itself inflames at a very low temperature; sulphur at a little higher, &c., so in a regular scale, evidently dependent on the relative strength of the affinities of these bodies for oxygen, and their consequent capability of taking it from the nitrogen with which it is combined in the form of atmospheric air. But perhaps the most striking confirmation of this theory, is what takes place with respect to certain burning bodies when plunged into the *nitric oxide*, which is a composition similar to the atmosphere, but its elements existing in different relative proportions, and therefore exerting different affinities on each other.

If we plunge a piece of phosphorus burning with a *pale blue flame* into this gas, it is instantly extinguished: the reason of this is, that at this temperature phosphorus has not a sufficient attraction for oxygen to enable it to separate that element from the nitrogen, with which it is combined, to form the nitric oxide. But if I plunge the same piece of phosphorus burning with a *white flame* into the same gas, it instantly decomposes the mixture, and burns as brilliantly as it would in pure oxygen. Its increased temperature has proportionably increased its affinity for oxygen, and it

is now capable of overcoming the affinity of oxygen for nitrogen.

I shall next proceed to prove to you, by experiment, that the *flame* proceeding from a burning body is hollow within; that is, it contains within it, no matter in actual combustion; and that it assumes the conical form, which it usually bears, in consequence of the pressure of the external air on the outward side of it. The flame, as it is called, consists of a *thin film* or *coat* of matter in a state of actual combustion, and this film is the only portion of the burning body which can properly be said to be in that state: I conceive that it assumes this appearance, at the precise instant the combustible body and the supporter of combustion enter into combination with each other. Immediately on taking this form it passes off from the quantity of combustible matter which exists within it; and which matter itself proceeds immediately from the main body which is supplying the whole; so that an object in a state of flame, seems to consist of matter under three several states or forms: first, the main body of the object which is gradually passing from a low to a high temperature; secondly, that portion of the object in question which has already reached that high temperature, but has not yet passed into a state of flame, because it is confined within the

external film of flame, and is therefore not capable of coming into contact with the atmosphere that is to supply it with its oxygen or support; and lastly, that portion which is in a state of actual flame, and is passing off from time to time, thus permitting another portion of that contained within it to assume a similar form. I conceive this external coat of flame to consist of the aggregate of points, where the two elementary substances, the combustible and its supporter, come into actual contact. Here they saturate each other, change their electrical states, become condensed, part with their light and heat, and their places are instantly supplied by the series of elementary atoms next in succession, both from within and from without, which meet, saturate each other, and pass off in a similar manner, till the whole combustible body is consumed; or till the process of combustion stops from some other cause.

If I have explained myself intelligibly, it will be seen that by this arrangement, and by no other, could the external atmosphere be prevented from mixing with the aeriform and combustible matter confined within the film of flame, and either causing it to explode at once, or dissipating it and changing its form and character. By the repellent property of the coat of flame, as well as by the

extreme tenacity of its texture, this is effectually prevented.

To prove that *flame is hollow*, and that the interior is filled with gaseous matter, at a low temperature; pour a little spirits of wine on a common plate, and inflame it; introduce burning phosphorus through the external film of the flame, and when so introduced it will be extinguished. Camphor, also, and a taper, become extinguished when introduced into the interior of flame. Inflammable substances, of any kind, will not burn within the interior of this film of ignited matter.

Draw a small wire across flame produced in the same manner by spirits of wine, or any other inflammable body, it will be seen to be *strongly ignited* at both sides where it intersects the film, but at no other point in the whole length; that part of the wire which passes through the interior, will be *scarcely heated*, at all events not to a visible red heat.

Drop carefully some spirits of wine on the surface of water, or within a small hoop or ring floating in a basin, set it on fire, and introduce your finger under the edge of the hoop and up through the water into the interior of the flame, you will perceive no heat whatever, unless you reach sufficiently high to touch the film itself.

To prove that the interior of flame consists of *gaseous matter*, waiting, as it were, its turn to

catch fire, introduce within it one end of a glass or other tube, a little inclined, the gaseous matter will escape through it, and may be inflamed at the upper end as it issues into the atmosphere.

Flame will not penetrate tubes of a certain diameter. It was on this hint that Sir H. Davy founded his experiments with regard to the *safety lamp*, and after framing several on various plans, he at length fixed on *wire-gauze* for the required purpose. The desideratum was a medium through which light would pass, but not flame: and it was indispensable that this medium should be inflammable in itself. Wire-gauze is nothing more than a series of tubes or apertures, through which flame will not pass; simply because its temperature is reduced below that of a white-heat, by coming in contact with the substance of which the said tubes are composed; for it is a law of nature that flame cannot exist below this temperature, and it necessarily follows that, on coming in contact with this reducing or cooling medium, it is instantly extinguished. It is clear, therefore, that the holes or apertures in the wire-gauze are simply to admit the passage of light, which is necessary for the workmen, and air, to support the taper within the lamp, without a possibility of explosion. It is obvious, also, that any medium which will reduce the tempera-ture of flame will have the same effect as wire-

gauze. Cotton-gauze, silk-gauze, or perforated paper, will have precisely the same immediate effect as wire-gauze, and the rationale of their action is precisely the same: but those substances being (unlike metallic wire) inflammable, they would presently take fire themselves.

The *fire-damp* which collects in mines is an inflammable body in a gaseous state, and bodies of this class, under common circumstances, will not burn without the presence of a certain temperature, and they will only burn suddenly, and, as it appears to our senses, instantaneously.

The fire-damp of mines consists of *carburetted hydrogen* and *atmospheric air*, and any substance, however large, if plunged into a volume of this gas in a state of *mere ignition*, as it is called, or at a glowing red-heat, will not produce any effect on it whatever; while the smallest possible spark or particle of any matter at a *white-heat*, or in a state of *flame*, causes it to explode at once. Consistently with this fact, the wire-gauze which occupies the place of glass in the safety-lamp, has been known to be red-hot, from the active combustion of the fire-damp within the body of the lamp, while the whole volume of fire-damp without the lamp remained unchanged, on account of the flame that is within the gauze not being able to penetrate through the perforations of it. For a human being to be working in a mine in

the midst of an immense volume of inflammable matter, by the light of a lamp, in this situation, affords a most striking example of the immediate presence, nay almost the immediate contact of perfect safety, and certain destruction. When we are sailing in the midst of the ocean, it is somewhat fearful to reflect that there is but a plank of wood between us and death; but here there is absolutely nothing intervening. It is demonstrable, or rather it is visible to the eye, that nothing intervenes between the flame within the lamp, and the destructive mass of combustible matter without, but an almost inconceivably thin film of this dangerous compound itself, which happens to be too cold for explosion. It is said that accidents from the fire-damp have sometimes happened, even when the safety lamp has been in use; but this must unquestionably be attributed, either to some defective construction in the particular lamp used, or to some want of care as to the condition, or the use of it. It is probable, that in these instances, some solid combustible matter which will take fire at a low temperature, (sulphur, for example), may have attached itself to the external part of the wire-gauze of the lamp, and the heat occasioned by the combustion of the damp within the lamp, may have communicated to this matter and ignited it: in this case the flame would of course communicate to the combustible

mass, and the whole would explode. In fact, extreme care is necessary in seeing that the outside of the lamp is free from any combustible matter of the above kind before it is used in the mine; and even during its use, for it may collect there at that time. As an illustrative experiment to prove this, apply a little sulphur, or phosphorus, to the outside of the wire-gauze of the lamp; in this state introduce it into a glass receiver; cover the mouth of the receiver with a piece of pasteboard, and press from a bladder, through a hole in the cover, a current of coal gas into the receiver, so as to mix with the atmospheric air it contains: this will form the exact mixture of fire-damp in mines, and in fact the *blower*, as the miners call it, will be represented by the jet of gas issuing from the bladder; this explosive atmosphere will burn safely within the lamp until the wire gauze becomes very hot; the sulphur, or phosphorus, will at length inflame, and consequently the whole gas in the receiver will explode.

The following experiments shew the action of *wire-gauze*, and the rationale of the lamp. Press wire-gauze *on flame* of any kind, and the flame will not pass through. The gaseous matter, however, which constitutes it, will pass through, and may be inflamed on this side, at the same time that a portion of it burns

below. These two portions will not communicate with each other, for if you pass any inflammable gas through wire-gauze, and inflame it on the opposite side, the flame will not communicate to the other. Place a piece of *camphor* on wire-gauze, and inflame it by holding a taper under it; the vapour will pass down through the wire-gauze and burn beneath it, but will not communicate through to the mass of camphor above.

Lay a *coil of platina wire* heated to *dull redness* on wire-gauze; at this moment pass any inflammable gas through the wire-gauze so as to impinge on the coil, it will instantly increase in temperature, as may be seen by its becoming *bright red*; but, in consequence of its contact with the wire-gauze, it will not retain a temperature sufficiently elevated to occasion inflammation of the gas, in virtue of the conducting and cooling power of the gauze: raise it a little, just sufficient to take it out of actual contact with the wire-gauze, and it will now, (on your continuing to press the inflammable gas upon it,) become *white-hot*, and inflame the gas. This sufficiently shews the cooling influence of the wire-gauze, which arises, no doubt, from its power of conducting heat away from the body in contact with it.

The introduction of a coil of platina wire, in the state of a simple red heat into the *vapour of æther*,

or any inflammable gas, offers to us an instance of *combustion without flame.**

The *products of combustion* are compound substances, formed by the union of the combustible body with the supporter. These substances are the same in appearance, and in chemical properties, as those produced by a union of the same elements, brought about by other causes, and by a different process. Thus, for instance, by burning *carbon* in *oxygen,* or in the atmosphere, we have a compound of carbon and oxygen formed: the carbon unites with a certain portion of oxygen, and the compound formed is *carbonic acid. Sulphur*, a combustible body, burned in *oxygen,* unites with it, and *sulphurous acid* is the product. *Hydrogen* burnt with *oxygen* forms *water*, and so of the rest.

When combustion is supported by *chlorine* intead of oxygen, the combustibles unite with it, and *chlorides* are formed.

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* See further remarks on this subject in the last Lecture.

LECTURE VIII.

OXYGEN, CHLORINE, IODINE, AND FLUORINE.

I NOW propose that we take a general view of the qualities and characters of those simple elements into which all known bodies may be resolved; or from which, by certain processes of nature, they are all produced. Those elements which we shall examine first are the four supporters of combustion; namely, *oxygen*, *chlorine*, *iodine*, and *fluorine*. So strong is the affinity of all these elementary bodies for caloric, as well as probably for light and electricity, that we have hitherto been unable to procure either of them in an uncombined state.

The simplest form under which they can be exhibited and examined, is that of an aeriform fluid, or gas; and it is under this form, therefore, that I shall first submit them to your attention.

And first with respect to *oxygen:* oxygen, in the form of oxygen gas, is perfectly invisible and intangible. It is highly elastic—possesses the mechanical

properties of air—is somewhat heavier than the common atmosphere, and is not in the least degree absorbed by water; and consequently may be collected over it, and preserved for an indefinite length of time.

Oxygen is procured generally, when wanted for common purposes, by heating to redness the *black oxide of manganese*, in an iron retort, or a gun-barrel. The oxygen separates in consequence of the intervention of heat between its particles and those of the manganese; by this means it is driven off from its combination in an aeriform state. It may be received over water, by affixing to the retort a copper or other tube, made air-tight, and placing the open end under the shelf of the pneumatic trough. It may be procured from *nitre* heated in an iron retort or gun-barrel in the same way: the last portions of gas, however, obtained in this manner are not so pure as the first, and it should therefore be tested by a match, to ascertain its purity, before it is received for use. It may also be procured from *red lead*, by the same means.

If manganese be mixed with sulphuric acid, and made into a paste, oxygen gas may be obtained from it, by heating it in a glass retort by the heat of a spirit or argand lamp. But the purest oxygen of all, is obtained by heating in a glass tube or retort some *oxymuriate of potass*;

and it should be obtained in this way when wanted for particular experiments. The gas obtained from manganese, however, answers for all common purposes, and may be received into wine bottles and corked up, and in this way kept any length of time.

Probably oxygen may fairly be regarded as without exception the most important substance existing in the economy of nature: the substance gifted with the most extraordinary qualities, and subservient to the most material purposes of animated as well as inanimate existence. It is the basis of that air which we, and nearly all other sentient beings breathe, and without which it is found that all animal life becomes speedily extinct. It has been calculated by Lavoisier, that a man consumes thirty-two ounces of oxygen gas in the course of every twenty-four hours; and when it is considered that a volume of this gas, which will fill the space of one hundred cubic inches, weighs no more than thirty grains, some idea may be formed of how vast a quantity of this material is required, and how perpetual a reproduction of it is necessary in order to answer the demands of a city like this.

If oxygen is not actually the "vital principle" of all animated beings, it at least offers the most probable solution of that problem, which has yet been given. The respiration of it—I mean of that

portion of it which is contained in the common atmospheric air—gives colour, fluidity, motion, and I may almost add life to the blood, which latter is thus enabled to convey these qualities to the various parts of the body, and without which none of them could exist for many moments. In fact, that oxygen has some mysterious connection with the vital principle, and through that with the mind, there can be no doubt, since the latter is affected in a peculiar and a most extraordinary manner, whenever the body is made to inhale either a more or a less than usual and natural quantity of it. This has been frequently proved by actual experiment. Oxygen is as necessary to vegetable economy as it is to animal, and is consequently doubly important to the latter, which, in fact, could not exist without the former. But oxygen is subservient to the purposes of vegetable life in a very different manner from that in which it is used by animals; and as this difference affords one of the most striking and beautiful examples of the consummate wisdom by which all the processes of nature are regulated, I ought not to omit noticing it here. When I just now stated the quantity of oxygen gas required for the support of one human being during one day, probably the question occurred to many, whence then proceeds that vast quantity which must be required for the whole circle of

animal life? I answer, chiefly from the vast and innumerable laboratories of it which exist in the vegetable kingdom. The upper sides of the leaves of plants, are their organs of respiration, and the gas which is constantly given out during the day-time by these organs, is *pure oxygen*, the very purest that can be procured. The two kingdoms are also made reciprocally useful in another particular, no less striking and important. The vital air of plants is *nitrogen* and *carbonic acid*, both of which are destructive to animal life, and which are given out in every breath which we expire. This, if not taken up by plants, would accumulate so as to render the atmosphere about us noxious and destructive: thus, what is *life* to one is *death* to the other, and *vice versâ*.

That plants give out oxygen may be shewn by experiment. Introduce a branch of rosemary under the receiver of the pneumatic trough, and expose it to the light of the sun; the gas will be found to pass up into the receiver in considerable quantities, and in a state of great purity. By some, and those not the least enlightened, this oxygen is believed, not to be a part of the vegeable, but simply a decomposition of the water effected by the action of the plant. Be this as it may, whether oxygen be produced by the decomposition of water, air, or rain, is of little consequence; for if it is liberated from its combinations

by peculiar vegetable laws, it does not affect the statement that we have just made.

Some aquatic plants possess this power of producing oxygen in very different degrees. In fact, all the tribes of the vegetable kingdom, differ in the extent of their power in this respect: hence, probably, the comparative purity of the atmosphere in different situations.

Oxygen is also found to be absolutely necessary to vegetation, in some of its most important processes. The saccharine matter of plants could not be produced without it; and it is the basis of all the acids that are found to exist in vegetables, and of which such important uses are made.

I shall now pass on to a consideration of oxygen in the union which it forms with other simple substances, and notice a few of the most striking results of this union. And first, with respect to *the metals:* with these oxygen unites in various definite proportions, and forms compounds, the qualities of which depend on those proportions. In the new chemical nomenclature, the great value and consequence of which I have before noticed, the names of these compounds are so constructed as clearly to point out the relative proportion in which the oxygen exists in combination with the metal. This is effected by arranging all those combinations of a metal and oxygen which do not produce an acid result,

under the general head of *oxides*, and then prefixing the first syllable of one of the Greek ordinal numerals, to indicate which proportion of oxygen obtains in the compound in question. Thus, where the first or smallest proportion of oxygen obtains, the compound is called a *prot-oxide*, the second is called the *deut-oxide*, &c. and when the largest possible quantity is present without producing an acid, it is proposed to call the compound a *per-oxide*. This rule applies equally well to the compounds formed by the other supporters of combustion with the metals, and also with other substances, for these terms are not confined to the combinations of oxygen, alone with the metals; but extend to combinations with all the other elementary substances which are capable of forming a union. Thus we have *prot-chloride*, *per-chloride*, &c.

Every union of oxygen with any other simple substance, supposing there is not a sufficient proportion of oxygen to produce either an acid or an alkali, is called an oxide. Nearly all the metals have a very strong affinity for oxygen; and in some of them this is so strong that they cannot be separated by any means hitherto employed. The splendid researches of Sir Humphrey Davy on this part of our subject, have left scarcely any doubt, that all those substances called *earths*, (which were, previously to his experiments, re-

garded as simple substances,) are combinations of oxygen with peculiar metals: that they are, in fact, *metallic oxides*. The same is also true of the *alkalies*, which are metals combined with a still further portion of oxygen. Of those metals which exist under ordinary circumstances in a metallic state, that which the most readily combines with oxygen is manganese, and from this metal it is usually obtained when wanted for the purposes of experiment. Those which the least readily combine with it, and which, when in a state of purity, will not combine with it at all, except at very high temperatures, are gold and platina. In combining with oxygen a metal gains an increase of weight exactly equivalent to that of the oxygen it takes up; and it loses its peculiar and specific characters, its brightness, malleability, &c., and becomes dull, brittle, pulverulent, &c. in proportion to the oxygen it takes up.

There are various modes of forming oxides of metals. One is, to heat them in contact with oxygen in a state of gas, when they fix the oxygen, taking it from the caloric with which it was previously combined: this has been seen in the experiment of burning iron wire in oxygen gas. They are formed, also, by placing the metals in contact with water, with atmospheric air, with an acid, &c. when the metals, according to their seve-

ral affinities, respectively decompose these substances, and uniting with the oxygen of them, suffer the other elements to escape. Finally, metals may be recovered from this state of oxidisement, and exhibited again in their pure and uncombined form. This is usually effected by the intervention of *fluxes*—one of which is *carbon* under the form of charcoal, which has so strong an affinity for oxygen that it will take it from almost any of its combinations.

To reduce a metal from an oxide to its primitive or simple state, it is mixed with a quantity of pulverized charcoal, and the two substances are placed in a crucible and submitted to intense heat. Under these circumstances the oxygen combines with a portion of the carbon, and passes away, or may be collected in the form of carbonic acid gas; and the metal thus disengaged from the oxygen, and not having any thing else present to combine with, falls to the bottom of the crucible in its natural form. It is not expedient to enter further into an examination of metallic oxides at present, as they will come more fitly under our notice when we speak of the metals themselves.

In its union with some of the other simple combustibles, oxygen offers a variety of most interesting and important results. The acids and alkalies, which are the chief of these, will demand a separate examination; all, therefore, that it remains

for us to notice here, are those combinations in which the oxygen does not obtain in that proportion which produces either of the above substances. Of these, the most important and universal, in their uses and applications, are the union of *oxygen* with *hydrogen*, to produce *water*, and the union of oxygen with *nitrogen*, to produce *atmospheric air*. The proportions of the first of these unions which obtains between the two substances in question, viz. to form water, are 85 parts by weight of oxygen, to 15 of hydrogen, in every 100 parts of the compound. I should observe that a second compound of oxygen with hydrogen has lately been discovered by the French chymists, and by them called the *per-oxide of hydrogen*, or *oxygenated water*; the method of forming it is a long and tedious process.

Nitrogen is capable of combining with oxygen in various proportions, but only in fixed or definite ones. The first or smallest portion of oxygen which unites with nitrogen, produces *atmospheric air*; this is composed of 78 parts of nitrogen, and 22 of oxygen, or 1 to 4 by volume: this compound it is unnecessary to examine here. The second proportion of oxygen which unites with nitrogen produces the *nitrous oxide*. This is composed of 63 parts of nitrogen and 37 of oxygen by weight, or 1 to 2 by volume; and has a

character not greatly different from that of atmospheric air, as it may be breathed by the lungs, not only without injury, but in some cases with beneficial, and in others with most curious and interesting effects. These effects seem to be in a great measure dependent on the constitutional organization of the person inhaling it. In some it produces fainting and insensibility, in others the most violent extravagance of action and sensation; and in others, indeed in all, it seems to produce the most pleasing effects of intoxication, without any of the after feelings of lassitude and debility which attend that state. It is said that Mr. Southey, the poet-laureate, breathed it, and declared that it produced in him sensations perfectly new and delightful. In fact, it unquestionably causes a species of intoxication; and it is to be feared, that the frequent use of it would be too apt to produce the mischievous, as well as the agreeable effects of that state. The nitrous oxide will, in some cases, support combustion, even better than common air; and phosphorus, as I have before had occasion to shew you, will burn in it with the same degree of splendour that it does in pure oxygen, but other substances, the flames of which are not at a sufficiently high temperature to decompose the compound, are extinguished when plunged into it, in the same manner as when they

are plunged into carbonic acid gas. The specific gravity of this gas is considerably greater than that of atmospheric air.

The third proportion of oxygen which combines with nitrogen produces the *nitric oxide.* This contains 57 parts of oxygen, and 43 of nitrogen by weight, or 1 to 1 by volume. This compound, like the former ones, is invisible; but, unlike those, it will not support animal life, though phosphorus will burn in it with great splendour, if previously inflamed. Immediately on coming into contact with atmospheric air, the nitric oxide assumes the form of a dense orange-coloured vapour, in consequence of the still further portion of oxygen, with which it spontaneously combines, becoming changed into *nitrous acid;* under this latter character we are to examine it hereafter. The nitric oxide is somewhat heavier than common air.

The various other important purposes not yet alluded to, to which this wonderful substance, oxygen, is applicable,—such as its influence in producing changes in colours, its being the base of all the acids, &c. will be noticed in their appropriate place.

Chlorine, and *Iodine*, the other simple supporters of combustion, resemble oxygen in these particulars also,—namely, that they are capable of producing *acids*, and that, when submitted to gal-

vanic influence, they are attracted to the *positive pole :* consequently their natural electrical states are negative. In examining the qualities of chlorine, I do not think it necessary to enter minutely into the history of the various changes which have taken place in the opinions of the philosophical world, relative to its having or not having oxygen for its base—its identity with the base of muriatic acid, &c. It is now pretty generally allowed to be a simple element; and I shall regard it as such, merely noticing that it is that substance which has long been known by the name of *oxymuriatic acid,* —a name peculiarly unfitted for it, since it is now demonstrated not to possess the qualities of an acid, but to be, in fact, a peculiar substance, gifted with qualities entirely its own, and capable of producing, by its union with other bodies, compounds that can in no other way be obtained. Chlorine resembles oxygen more than any other substance does, being capable of supporting combustion, and of producing acids. As it is a highly curious substance, however, and the opinions respecting its nature have been varying ever since it has been known, it may be useful to state thus much with regard to its history; namely, that it was first discovered by Scheele in 1774, who called it *dephlogisticated muriatic acid ;* that the term *oxymuriatic acid* was afterwards applied to it by the French chemists, on the supposition that it con-

sisted of muriatic acid, joined to a portion of oxygen: that since then it has been known by that name, and the various salts which it is capable of forming with other substances have been called *oxy-muriates*, on the general principle of the new nomenclature: and, finally, that a few years ago Sir H. Davy instituted an inquiry into its nature, and has stated it to be a distinct element, with peculiar qualities of its own, and given it the name of *Chlorine*, which it now bears; and the compounds which are formed by the aid of it, are consequently denominated *chlorides*, *chlorites*, *chlorates*, &c. according to the proportions in which it exists in them, and the nature of the union.

Chlorine is obtained in the form of a permanently elastic fluid, or gas; it may, however, be solidified by intense cold, and under strong mechanical pressure. It is visible to the eye, being of a greenish colour, from which circumstance it takes its name. It has a pungent and extremely disagreeable smell, and is highly injurious to animal life if respired.

Chlorine is obtained by heating in a retort the black oxide of manganese and muriatic acid, made into a thin paste: it may be received over cold water in the usual way, although it becomes absorbed by it if suffered to remain any length of time; it is very disagreeable, and I believe injurious to the lungs, even when largely mixed with at-

mospheric air; therefore the first portions which come over mixed with the air contained in the retort, should be received in an air jar, and decanted out of doors, or in some situation where it may escape, and not be allowed to mix with the atmosphere of the room.

Some substances, when plunged into chlorine in an ignited state, are speedily extinguished; while others, and those the least combustible of all substances, present the extraordinary phenomenon of spontaneous combustion. This is the case with several of the metals—even with gold itself—on being plunged into it, they burst into actual flame and burn with great brilliancy; and the result of this combustion is a compound of the two elements, viz. the metal and the chlorine; and as a similar union with oxygen produces *oxides*, so, on the same principle, the combinations effected in the above process should be called *chlorides*. It is doubtless, a most extraordinary fact, that a burning taper is almost immediately extinguished by this substance, and yet that the bodies which cannot be made to burn even in pure oxygen without previously raising their temperature very high, should spontaneously consume with a brilliant flame in this gas at the common temperature. Chlorine is capable of uniting with various proportions of oxygen. With the first proportion it forms an oxide of chlorine,

called *euchlorine* by its discoverer Sir H. Davy: it is in the form of a gas, and is absorbable by water, so that it cannot be collected except over quicksilver. The next proportion of oxygen and chlorine produces *chloric acid;* which, by its combination with other substances, produces salts. These salts are many of them extremely important and interesting in their nature, and have long been known under the name of *oxy-muriates:* they should now more properly be called *chlorates.* The third, or last proportion of oxygen which will unite with chlorine, produces what has hitherto been called *hyper oxy-muriatic acid*, but which should be called *per-chloric acid.*

Chlorine combines with *hydrogen*, and forms *muriatic acid.* A mixture of these gases, in the proportions of 1 to 1, may be fired by inflaming them together by means of the electric spark, or by exposing them to the direct rays of the sun. When the product, if tested, will be found to be *dry muriatic acid.*

The best method of showing the effect of chlorine on the metals, is to introduce into a retort or flask, with a cap affixed, some copper leaf, and then exhaust the atmospheric air by an air pump or syringe, and admit chlorine gas in its stead: the copper leaf will instantly take fire, and burn with a singular and beautiful effect. Instead of copper leaf powdered antimony may be used, or

zinc leaf. Gold, silver, &c. may also be burnt in the same manner, but they require to be heated a little, previous to the admission of the gas.

In case the student is not possessed of an air pump or exhausting syringe, a tall jar or glass tube may be filled with chlorine, over the trough in the usual way, and the metal to be experimented on thrown into it. In a long tube, the appearance produced by filings of antimony is extremely beautiful, appearing, as it does, in a shower of fire.

The best means of preserving chlorine, as it cannot be kept over water, is in glass stopper bottles: the stopper should be smeared with grease or cerate, to make it perfectly air tight. The gas may be kept for some time in this state, without injury. Chlorine has the property of *discharging colours* provided water be present, as it effects this by decomposing the water. Introduce into a jar or receiver filled with chlorine, a piece of printed calico or coloured linen cloth: if it be perfectly *dry*, no action or effect on the colour will take place; but if it be previously *wetted*, it becomes almost instantly bleached.

Iodine, though curious in its nature, has not hitherto been applied to any very striking practical purposes. Like the foregoing substances, it is attracted to the positive pole of the galvanic battery, which fact may be taken as a proof of its resembling those bodies in other respects;

and, accordingly, it is found to be capable of producing acids, and of partially supporting combustion; though the experiments which may be given, in order to prove these facts, are at present somewhat equivocal. Indeed, this substance has hitherto not undergone sufficient examination to entitle us to speak of any of its qualities with perfect confidence; I shall therefore decline submitting to you any further remarks on it.

Of *Fluorine*, the other supporter of combustion, very little is positively known, since it has never yet been detected in an uncombined state; it is merely on conjecture, therefore, that it has obtained a rank among elementary substances. It is generally found in combination with hydrogen, forming *fluoric acid*. This latter is obtained by heating together fluate of lime and sulphuric acid. Fluorine has a strong attraction for silex, and on this account the gas containing it has been used for etching on glass. In combination with *boron* it forms *fluoboric acid.*

LECTURE IX.

OF HYDROGEN, NITROGEN, CARBON, PHOSPHORUS, SULPHUR AND BORON.

Having, in my last lecture, directed your attention to the simple supporters of combustion, I think it a desirable arrangement immediately to follow these by a consideration of those simple bodies which are at once combustible, and which combine with the supporters of combustion to form that important class of bodies termed acids. Of these simple combustible, or, as they are sometimes termed, *acidifiable bodies*, the most important are *hydrogen*, *nitrogen* and *carbon*; but there are also three others which merit great attention: namely, *phosphorus*, *sulphur* and *boron*. I shall speak of these in the order in which I have named them; and I greatly fear that the limits of a single lecture will not afford me occasion to examine them in any thing like an adequate and satisfactory manner; but, in the arrangement that I have thought it expedient to make, it was not possible for me to afford them any greater space.

Hydrogen is so called from its property of generating water, of which fluid it is one of the two constituent parts, as we have before seen in our examination of the other constituent of water, oxygen. It is not necessary for me here to repeat what I then had occasion to say of hydrogen in this point of view; I therefore pass on to its other important characteristics and qualities. The only form under which we are capable of examining this substance is, in that of an aeriform fluid or gas, into which it is resolved by its union with caloric. In this form hydrogen is the lightest, and at the same time the most inflammable of all known bodies. It extinguishes flame; the inhaling it is fatal to animal life; it has no attraction for water, and may therefore be collected over that fluid; is invisible, and has an unpleasant smell, even in its purest state. Hydrogen gas is nearly fourteen times lighter than common atmospheric air, and is therefore capable of supporting other substances in the latter fluid: it is therefore used for the purpose of raising balloons; but this singular quality of it has not yet been applied to any other practical purposes. It is, however, probable that some of the most beautiful and curious phenomena of nature owe their existence to this quality of hydrogen, added to its inflammability. It is likely that the *aurora borealis*, as it is called, consists of hydrogen gas, sustained at a certain

elevation in the air in virtue of its lightness, and ignited from time to time by electricity. The *ignis fatuus* also consists chiefly of hydrogen in combination with phosphorus, generated by the decomposition of vegetable matter, and lighted by the heat given out during the act of decomposition. There is one other very curious quality belonging to hydrogen gas: when burnt within a glass tube, under certain circumstances, it gives out a clear and distinct musical sound. This is said to be occasioned by the rapid succession of detonations attending the union of the oxygen and hydrogen during combustion; because if inflamed suddenly after being mechanically mixed together, these gases always detonate—that is to say, they unite so rapidly, that, to our senses, the union seems instantaneous; and it produces the same effect on the surrounding air as the explosion of any solid detonating mixture does.

It may be well in this place to mention a property which is possessed by hydrogen and all other elastic fluids, in which they strikingly differ from incompressible or inelastic fluids, such as water, oil, &c. If water and oil be mixed together, the oil being of a less specific gravity than the water, rises to the top and remains there; but it is not so with elastic fluids, though hydrogen gas is fourteen times lighter than oxygen gas: yet if they come in contact with each other under any

Plate 6.

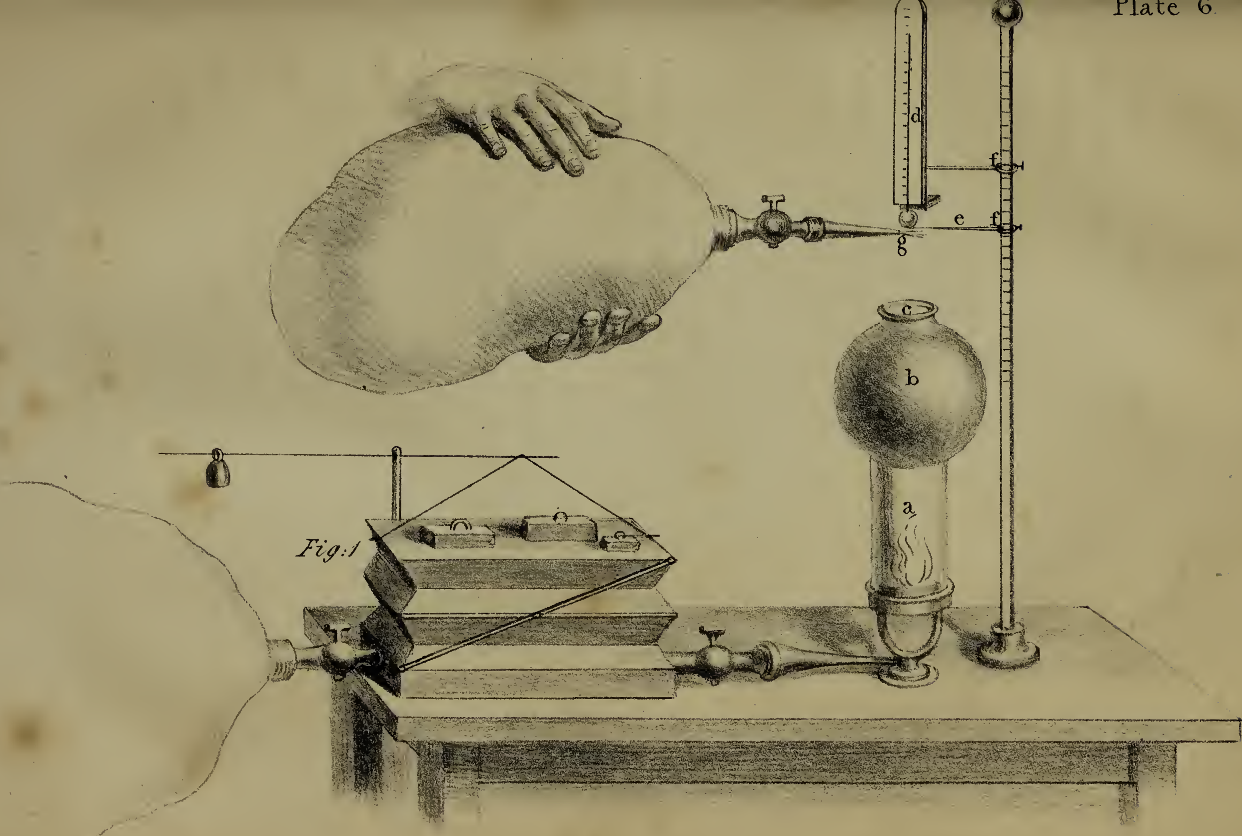


Fig: 1

Drawn by the Author

G. Scharf Lithog.

London. Pub: by G. & W. B. Whittaker. Ave Maria Lane, 1823.
Printed by C. Hullmandel.

circumstances, they cannot be prevented from diffusing themselves through each other, and becoming completely mixed. If two vials, the one filled with hydrogen, and the other with oxygen, be connected together by a glass tube of extreme small bore, which shall perforate the corks of each, so as to make a free communication between them, even if the hydrogen be inverted over the oxygen, or in whatever situation they may be placed with respect to each other, it will be found that, after a certain time, the gases have united together in equal proportions; for on removing the corks and applying a light to the mouths of the vials, they will both of them explode. It is a considerable time, probably two hours, before this union takes place. As it is probably known to almost every one present that it is to hydrogen combined with carbon we are indebted for the present beautiful manner in which our streets, houses, theatres, &c. are illuminated, I shall not occupy your time by doing more than thus cursorily noticing its application to this important use, but shall proceed to state, that probably its next most important practical application is as a means of fusing and burning all known bodies, by uniting it with a certain portion of oxygen gas, and then submitting the body required to be burnt to the influence of a stream of these united gases.

We shall now proceed to some experiments in

confirmation of what I have stated. First, in regard to the lightness of hydrogen gas. Blow soap bubbles with it from a tobacco pipe, and they will rise in the atmosphere and float to a considerable height. Hold a jar with its mouth upwards, containing hydrogen gas, it will raise rapidly, as may be seen by holding a taper considerably above it, when it will inflame.

Issue from a long jet a stream of hydrogen gas; inflame it, and invert over it a glass tube of about half an inch in diameter, a *peculiar musical tone* will be produced. I find the same effect is produced by burning hydrogen, or carburetted hydrogen—coal gas—in the neck of a wine bottle: at first no tone whatever is heard, but as soon as the oxygen it contains is combined, and the flame calls on the atmosphere without for support, the musical tone commences. This tone appears to me not to be occasioned by a series of detonations, as is generally stated, but by a mechanical action of the air on the lips or mouth of the bottle: so also in the case of the tubes; for the tone which is produced from both is of the same quality as that produced by blowing into them. If the tone is occasioned by a series of detonations, the quality would be governed by the *rapidity* of those detonations, and not by the *depth* of the bottle. The latter invariably regulates the pitch of the tone, when thus produced. The situation also of the flame

confirms this idea; for it must be so placed that the angle, formed by the current with the mouth of the tube or bottle, does not differ from the one necessary to produce tone by common blowing. This also accounts for the length of tube required to produce tone; for should the current be slow, a length of tube equal to two feet will be necessary. As the angle is made to change, or as the current varies, so also the tone varies from the fundamental, to the fifth, third, &c.; again, a short tube will not produce a tone at all, unless a very strong current is made from below upwards, either by rarefaction or by combination. In a large stone bottle or jar the tone is similar to the lowest tone of the violincello; and in all the experiments I have made, the true tone from hydrogen gas is always governed by the size and depth of the tube or bottle, agreeable to the laws observed in other sonorous bodies.

Hydrogen unites with *fluorine*, and forms the *fluoric acid;* with *iodine* it also forms an acid, the *hydriodic acid.*

Hydrogen is procured for experiment by pouring on iron filings, or on zinc, in a retort, diluted sulphuric acid. It is received over the pneumatic trough in the usual manner.

Nitrogen must unquestionably be regarded as a most important agent in the economy of nature, since it is not only one of the component parts of

the vital air of all animals and of all vegetables, but it in fact forms the chief constituent of all animal substances. It is probable that the office of nitrogen, in its mixture with oxygen in the air we breathe, is simply to dilute that substance, which would otherwise act upon the animal functions like ardent spirits, causing a degree of action and irritability that would amount to disease, and produce speedy death. It is in virtue of this diluting and neutralizing quality of nitrogen, that it has been used with success to allay increased irritability, inflammation, &c.; and there can be little doubt that, after due experience of its powers in this respect, it may be rendered still more important as a medicinal agent. That it is chiefly in virtue of this diluting quality of nitrogen that it is made to form a part of our vital air, is the more probable, since nearly the whole which is taken into the lungs with the oxygen is again expired. There are, in connection with this fact, two beautiful provisions of nature, which I will here notice for the benefit of the younger part of my audience. Nitrogen gas being of itself *noxious to animal life*, and yet being perpetually expired by all animals in an uncombined state, if some arrangement were not made to get rid of it from the immediate neighbourhood of the region in which we breathe, the whole air must speedily be contaminated, and unfit to sup-

port life. To provide against this, a double provision has been made: there is always a short interval between the separate respirations of all animals; and during this interval the nitrogen gas, being gifted with a degree of levity superior to that of common air, or of oxygen, mounts up into the higher regions, thus admitting the common air to take its place opposite our mouths, and preventing all danger of our again taking in what was breathed out, precisely because it was unfit to benefit and sustain our animal functions.

Nitrogen gas is procured generally by distilling animal substances. It comes over in very large quantities, and may be received over water. Animal substances are chiefly composed of nitrogen: whence, then, is it that animals which feed entirely on vegetables, (which we know contain, with one or two exceptions, not a particle of already formed nitrogen) derive that of which their bodies chiefly consist? It cannot be through their food that they obtain it; neither can it be through the medium of the atmosphere, since animals expire as much nitrogen as they inspire, in every interval of respiration. We cannot imagine it to be received from the atmospheric air through the skin; this latter is a supposition that cannot be entertained.

Nitrogen, I suspect, is a peculiar compound, formed by the organs of the animal body, and not a simple element, as is generally supposed;

when it is submitted to *galvanic influence*, it neither goes to the one pole or to the other, but holds almost a neutral situation between the two: this circumstance strengthens the suspicion that it is a compound, and not a simple element. Nitrogen is the base of all *fulminating compounds;* and it would seem that the strong bands of affinity between its elements are broken in detonation: which perhaps is the cause of this peculiar phenomenon. The new compound, the per oxide of hydrogen, detonates when dropped on silver, &c. by which its elements become separated, analogous to the fulminating compounds, formed with nitrogen.

Under strong suspicion that nitrogen is a compound, and not a simple element, I am now prosecuting a series of experiments with a view of satisfying my mind on this subject: they are chiefly directed with a view, first, to preserve the products of detonation under strong mechanical pressure; secondly, to examine them attentively and accurately; thirdly, to effect a combination of nitrogen or its elements, with other substances, under immense mechanical force: and from the experiments I have already made, I am disposed to believe that it is not a simple substance, but a compound of oxygen and hydrogen, nearly in equal proportions.

I now proceed to notice *Carbon,* another of the

simple inflammable and acidifiable substances. I will first mention that carbon exists, in a very small proportion, in atmospheric air; that fluid contains about one part in every hundred, in the form of carbonic acid gas. The utility of this combination has not yet been made apparent; but as it is expired by the lungs in the same manner as nitrogen is, and has also the same noxious qualities as that substance, a similar beautiful provision has been made for getting rid of it: for, being twice as heavy as the common atmospheric air, immediately on being expired it sinks to the earth, as the nitrogen ascends from the earth, and we are thus kept out of danger from either. It is generally considered that carbonic acid gas is chemically combined with the air of which our atmosphere is composed, on account of its being found at the greatest heights; but I conceive this to be an error: it probably exists at those heights, in virtue of that quality which we have before stated to belong to all permanently elastic fluids; namely, that of interfusing themselves equally among each other, whenever they are in contact.

Carbon is unquestionably a most curious and interesting substance. The only pure form under which it is found to exist is that of the *diamond;* and to this state of purity no processes, but those of nature, have hitherto been capable of reducing it. But that, by some future process of our art, we

should arrive at the power of forming the diamond, is by no means impossible; and if the pseudo-philosophers who used to engage in the idle search after a menstruum that would change other metals into gold, had endeavoured, instead, to form the diamond, their search, though perhaps equally idle, would certainly have been much less ridiculous and unphilosophical, since this latter desideratum is evidently within the bounds of possibility; whereas, to change one simple substance into another, is contrary to the nature of things, and therefore physically impossible. Carbon exists in a greater proportion in *charcoal* than in any other known combination, and the purest form of charcoal is the substance called *lamp-black.* Charcoal contains 64 parts of pure carbon, united to 36 parts of oxygen, in every hundred parts; and is, without exception, the most indestructible of all compounded bodies. Though highly inflammable, yet when excluded from the presence of further oxygen, it remains absolutely unchanged by the most intense degree of heat that can be applied to it; and it appears that, when excluded from the air, the hand of time has no power upon it whatever. Some years ago, some pieces of *charred wood* were taken from the bottom of the Thames, which had unquestionably been placed there for a particular purpose during the time of Cæsar; and it was found, not only that

their external form remained unchanged, but that the uncharred part of the wood at the centre was as sound as if it had been placed there yesterday. Charcoal, though consisting entirely of carbon and oxygen, has yet so powerful an affinity for a still further portion of oxygen, that it will, at a certain elevation of temperature, attract it from all other substances. It is in consequence of this affinity that it burns with such intense vividness and brilliancy in oxygen gas, and also when placed in the flame of the oxy-hydrogen blow-pipe. The first compound of carbon and oxygen is the *carbonic oxide*, which is an inflammable gas; the proportions are one to one. The next portion of oxygen gained by this union reduces it to *carbonic acid*, a compound of two to one, under which form we shall have occasion to examine it hereafter. The other combinations of carbon with other of the simple substances, give results highly important to the arts and to science, but it would be going out of our appropriate course to examine them here. But we must not neglect to notice the various and important uses to which this substance is applied in the economy of nature. Carbon forms nearly the whole body of the *vegetable kingdom*, and is by far the most important ingredient of all those substances which we derive from that kingdom; such as *sugar*, *gums*, *resins*, *oils*, &c. It is also nearly the sole consti-

tuent of that inexhaustible fund of *fuel*, without which it is difficult to conceive how man could exist at all, and without which it is quite certain that he could not exist in a state at all approaching to civilization. Combined with mineral substances, carbon also forms an important part of the solid body of our earth. It is one of the chief ingredients in all *marble*, *limestone*, &c., and gives their peculiar character to those very rocks and cliffs which form an impregnable barrier round the island which we inhabit, and render it inaccessible to the inroads of any foreign enemy, or even of the ocean itself. Besides acting these important parts, carbon forms the chief sanative ingredient in many of our *mineral waters;* and it is from their union with carbon, that *hydrogen gas* and those other gases which are given out from our candles, lamps, &c. owe their power of giving light.

Phosphorus, the next subject of our examination, exists in a solid and uncombined state; though it has not hitherto been found in this state in nature. It is the most inflammable of all solid bodies; that is to say, it takes fire at a lower temperature. It will inflame spontaneously on being placed in contact with hot water. Phosphorus has also the peculiar quality of emitting light, even when not undergoing combustion, and which light is visible when not overpowered by a greater. In a dark

room, the hands or any part of the body, if rubbed with this substance, appear highly luminous. The presence of atmospheric air seems, however, essential to the existence of this quality: since phosphorus is not luminous when confined in nitrogen, or even in oxygen gas ; which latter fact, in particular, proves that the luminous appearance of phosphorus does not arise from its being perpetually in a state of slow combustion, as has been conjectured by many. Phosphorus combines readily with nearly all the metals, and with most of the other simple substances, forming particular compounds, which will be noticed in their place. Phosphorus seems to be exclusively an animal product, and to be generated, or at least to make its appearance, during the conversion of vegetable and mineral into animal matter, and to have some mysterious connexion with animal life. In proof of this, it is found that several animals possess the power of generating and giving forth this substance at will.

Some of these animals are well known, such as the *glow-worm*, the *fire-fly*, &c. but by far the most curious and striking of them is one which has hitherto been very little noticed or described; it may therefore be interesting, if I extract a short account of it. It bears the name of the *pyrosoma atlanticum;* and is thus described by Monsieur

Peron, as observed by him in his voyage from Europe to the Isle of France:

"The darkness was intense when it was first discovered, the wind blew with violence, and the progress of the vessel was rapid. All at once there appeared, at some distance, as it were a vast sheet of phosphorus floating on the waves, and it occupied a great space before the vessel. The vessel having passed through this inflamed part of the sea, the crew discovered that this prodigious light was occasioned entirely by an immense number of animals, which swam at different depths, and appeared to assume various forms. Those which were deepest looked like red-hot cannon balls; while those on the surface resembled cylinders of red-hot iron. Some of them were soon caught, and they were found to vary in size from three to seven inches. All the exterior surface of the animal was bristled with thick long tubercles, shining like so many diamonds; and these seemed to be the principal seat of its wonderful phosphorescence. In the inside also there appeared a multitude of little oblong narrow glands, which possessed the phosphoric virtue in a high degree. The colour of these animals, when in repose, is an opal yellow, mixed with green; but on the slightest movement of those spontaneous contractions which it exercises, or those which the observer can at pleasure

cause by the least irritation, the animal inflames, and becomes instantly like red-hot iron, and of a most brilliant brightness. As it loses its phosphorescence it passes through a number of tints successively, which are extremely agreeable, light, and varied; such as red, aurora, orange, green, and azure blue: this last shade is particularly lively and pure." This is by far the most curious account of phosphorescent animals that I have ever met with.

The two remaining subjects of this Lecture are *sulphur* and *boron*.

Sulphur, like the substance just examined, is highly inflammable, and is the base of one of the most powerful of our mineral acids. It is found in nature very plentifully, both in a pure state, and mixed with metals in the form of ores, or sulphurets; and it has the quality of subliming, or passing off in the form of fumes, at a temperature of about 280°. If collected in this state, and examined with a microscope, it is found to consist of minute crystals, but its appearance to the eye is that of an impalpable powder: in this state it is usually called, *flowers of sulphur*. Sulphur forms a union with nearly all the simple substances, in different proportions; and many of the results of these unions are highly useful in the various arts, manufactures, &c. These combinations will be examined and illustrated in other

parts of our course. At present I shall only have time to shew you the qualities of this substance in its simple state. Previously to which, however, it may be as well to notice the little that is at present known, with regard to the other simple acidifiable base—*boron.*

"This substance is obtained by heating the metal called potassium in contact with boracic acid, previously reduced to a state of powder. The potassium having a stronger affinity for the oxygen of the boracic acid than the boron itself has, takes it from that substance, and leaves the latter in a state of purity. In this state it is a brown insipid powder, which remains unaltered under common circumstances, but which, at a temperature of 600°, burns with much brilliancy, especially in oxygen, and in this latter case produces boracic acid again. This substance communicates a green colour to certain flames. It is not found native in an uncombined state, and its combinations have hitherto been applied to few practical purposes."

LECTURE X.

ON THE METALS AND EARTHS.

It is our business, in this lecture, to take a cursory view of those natural substances called *metals* and *earths*: to state their distinguishing external as well as internal characteristics, their chemical qualities, and some of the principal purposes to which they are applicable. The general qualities by which the *metals* are distinguished from other bodies, are these: their superior specific gravity; their malleability, or capability of being beaten or moulded into any given form; and that external appearance, which is called their lustre or brightness. Their chemical qualities are various and important. United to oxygen alone, they form a variety of oxides, which are of the greatest utility in the arts and in chemistry; and united to oxygen, and the base of the various acids, they form a multiplicity of saline bodies, which are of the last importance in medicine, and of infinite advantage in acting as agents, tests, &c. in our various chemical researches. The important use of the

metals, in their metallic state, must be obvious to every one; but perhaps few have contemplated the subject sufficiently to enable them to see (what is nevertheless unquestionably true), that without them we could never have reached our present state of civilization, and that, if we were deprived of the use of them, we could no longer maintain ourselves in that state, or in one at all approaching to it: they in fact form the foundations of almost all the useful arts of life. It would be going out of our way to prove this; and it is perhaps quite needless to do so, since a very little reflection will convince most of my hearers of the truth of what I am stating.

In examining the metals individually, it will be expedient to take a somewhat detailed view of a few of the principal ones, and to pass over the others with a very slight notice; as to do more than this would require the space allotted to two or three whole lectures, instead of the half of one, which is all that I am enabled to devote to this part of our subject. The metals that I shall examine most in detail, are *gold*, *platina*, and *silver*. The next in importance to these I shall treat of less in detail, but still somewhat copiously, as they present many points of great interest and importance: these are *mercury*, *copper*, and *iron*. The remaining metals are *tin*, *lead*, *zinc*, *nickel*, *cobalt*, *arsenic*, *manganeze*, *bismuth*, *anti-*

mony, and eight others, the names of which I shall mention hereafter, but shall have scarcely any thing to say about them, as their uses and properties are at present but little known. In this enumeration I have not included the two most interesting newly discovered metals, *potassium* and *sodium*; as I have thought that, upon the whole, these will be more advantageously examined when we come to treat of the alkalies, of which they form the base. I have chosen this arrangement, the rather because these peculiar metals may in one sense be regarded as artificial productions, since they are never found to exist in nature in a metallic state.

Gold, the most valuable of the metals, is the heaviest of them all except platina; is exceedingly ductile; it has at a common temperature so little affinity for oxygen, that it never tarnishes, and is frequently found in nature in a state of perfect purity. The malleability or ductility of gold is its most extraordinary property. In virtue of this property it may be spread over other substances in such inconceivably thin films, that it would require fourteen millions of them to make up the thickness of one inch. This comparative thinness will appear more striking, when I state to you that the same number (*viz.* fourteen millions) of leaves of common writing paper would make up a thickness of nearly a quarter of a mile.

It has been calculated by the French chemist Fourcroy, that a silver wire thirteen hundred miles long may be entirely covered by one ounce of gold. Gold is also of extreme tenacity; a wire of it, not more than one tenth of an inch in diameter, being able to support a weight of five-hundred pounds. Though gold has little attraction for the chief supporter of combustion, oxygen, yet it has so strong an attraction for another of the supporters, chlorine, that, on being plunged into it a little heated, it takes fire spontaneously, and burns with great brilliancy. The chief sources from which gold is procured are Africa and South America, particularly the latter, where it is found in large quantities. There is at present, (or at least was a very few years ago) a single mass of native gold, in the royal cabinet at Madrid, which weighs one hundred and thirty-two ounces. This was found by the Spaniards (together with a vast quantity more in the same state) in an open plain in the province of Sonora, in South America. It is also found in the sands of rivers, washed down by the floods. Gold is also found in small quantities in Cornwall; generally in a pure state, and in small grains. It is found principally in the refuse of the old tin mines, by the streamers, as they are called, whose perquisite it is: they receive it into quills, which when full, they carry to the goldsmith, and get very nearly the value of pure gold for it.

Traces of it are also evident in many of the copper-mines.

It has been found in this state in Africa, also in France, Ireland, and Scotland; in Ireland, in particular, a mass was once found weighing twenty-two ounces. In consequence of its attraction for the base of muriatic acid, or chlorine, gold may be dissolved and held in solution, and it may also be reduced to oxides. We shall not have time to examine the substances thus formed, and the saline bodies which may be made to result from them, but may mention, in passing, that the oxides of gold form very beautiful pigments, and are of great use in the arts; and that one of the peculiar bodies resulting from the union of gold with an acid, possesses an extraordinary fulminating or detonating power: it explodes on the slightest touch, and is highly dangerous in its consequences if not used with great caution. As many other substances, and all the other metals, are capable of attracting oxygen from gold, this property has been applied to some very pleasing experiments. If satin, silk, paper, &c. be covered with a solution of gold in nitro-muriatic acid, and then exposed, while moist, to the action of hydrogen gas, the oxygen that was united to the gold goes to the hydrogen, and leaves the metal in a state of purity. In this manner any ornamental figures in gold may be laid on to various substances. I

should perhaps mention, that when gold is used for most common purposes, it is alloyed with a small portion of either copper or silver, as without this it is too soft to be worked with convenience or advantage.

Gold from aqua regia (nitro-muriatic acid) may be suspended in strong sulphuric æther, by mixing the two liquids together, and after agitation suffering them to rest and separate; the æther will combine with the gold, and float on the surface, in virtue of its specific gravity. If polished steel be moistened with this æthereal solution of gold, it will become covered with a thin coat of metallic gold, of beautiful appearance, and also of great advantage in protecting the object so covered from the corroding effects of the damp atmosphere.

Silver, like gold, is exceedingly ductile; a single grain of it may be beaten out till it covers a surface of fifty square inches. When in a state of purity it has very little attraction for oxygen, at a common temperature, but may be made to unite with it at a high one, or by the intervention of an acid, forming two distinct oxides, the grey and the white. In union with other of the simple substances, silver forms several highly curious and useful saline bodies, such as the nitrate of silver, the muriate of silver, the sulphate, carbonate, &c. Several of these are found in nature, others are

procured by artificial means alone. Some of these salts are highly useful as chemical tests; and one of them, the *nitrate of silver*, is so powerful an antiseptic, that a single ounce of it dissolved in twelve hundred ounces of water will preserve the water in a state of purity for ever. The nitrate of silver is deleterious in its effects on the animal system; but when the water thus preserved is needed for use, the whole of the silver may be separated from it in a few minutes, by adding a small portion of muriate of soda, or common salt.

The muriate of silver is insoluble in water, consequently it cannot be diffused through it. Silver has so strong an affinity for muriatic acid, that it becomes an exceedingly delicate test for its presence: if solution of silver be dropped into any mixture containing muriatic acid, it instantly combines with it, and precipitates in the form of an insoluble white powder. Take a pint of pure water, into which drop two or three drops of muriatic acid, add to this two or three drops of solution of nitrate of silver; the silver will be precipitated instantly in combination with the muriatic acid, having left the nitric acid with which it was previously combined, in virtue of its stronger affinity for the muriatic.

The indelible ink used for marking linen, &c., consists chiefly of nitrate of silver. There is also a compound of silver with nitric acid, which

has extraordinary fulminating qualities, and is highly dangerous in its effects. Silver is found, both native and combined, in various parts of the world: in combination with sulphur, forming a sulphuret of silver; with carbon, forming a carbonate; with oxygen, forming an oxide, &c. In the uses to which silver is applied in a metallic state, it is found necessary to mix a small portion of copper with it, to render it more hard and durable.

Platina is the other and last of what may be called the precious metals. It is the heaviest of all known substances; it is infusible except at a very high temperature, has no attraction for oxygen under common circumstances, and is not affected in the slightest manner by any of the mineral acids. All these qualities render it of most important service in the arts, but most particularly in chemistry, which owes some of its finest discoveries to the existence of this metal, as without its aid those experiments could not have been made which have led to the discoveries in question. Platina has not been known in this country more than seventy years; it was brought from Jamaica by an Englishman named Wood, and by him experimented on, and described in the Philosophical Transactions for 1749 and 50. It is extraordinary that the ore in which platina is found contains nine different substances, namely, platina, iron,

lead, copper, silex, and four substances which are never found under any other circumstances: these have been called osmium, rhodium, iridium, and palladium. By some they are considered to be entirely new and peculiar metals; but it seems probable that they may turn out to be alloys of other metals, since they are found no where but in the ore of platina. The only acids which affect platina are those which also affect gold, namely, the oxymuriatic and nitro-muriatic acids: in other words, it is only soluble by the intervention of chlorine, which is the base of these acids. By means of these it may be made to form salts and oxides; but these combinations of it have not been hitherto applied to any very valuable purpose. The grand utility of platina belongs to it in virtue of the qualities it exhibits when in a metallic state, and these are almost exclusively applicable to chemical purposes. Platina fuses at a comparatively low temperature when mixed with arsenic. In this way it may be cast into ingots, &c., and the arsenic driven off, as much as is necessary for common purposes, by means of a strong blast furnace.

Mercury, the next metal in our list, is, at the common temperature of our atmosphere, always in a fluid form, when unmixed with other matters: this arises from its strong attraction for caloric. By certain processes, however, it may be deprived

of its caloric, and then it exhibits the qualities of other metals, being like them solid and malleable. It possesses the lustre of a metal in either state, and more when liquid that when solid. Mercury is found both native and combined, in many parts of the world, in South America, in Spain, in Germany, Sweden, &c. It is said, also, that marine salt is never found unmixed with mercury: certain it is that the muriatic acid of commerce (which is made from sea-salt) always contains a portion of corrosive sublimate, which is an oxide of mercury; and there is no means of accounting for its presence but by supposing it to have existed in the sea salt. Mercury possesses the property of subliming, or passing into vapour, at so low a temperature, that it may be distilled like any other liquid. With oxygen and other substances, mercury forms compounds which are of the greatest value and importance in medicine; the principal of these is calomel, which is a sub-muriate of mercury, or, in other words, a combination of mercury with chlorine. Mercury is also used in large quantities in gilding, in silvering looking-glasses, &c.; the process by which it is made available in gilding is interesting from its simplicity. Gold, in a state of purity, is triturated in contact with mercury, and the two metals thus form an amalgam, or soft mass; this mass is laid regularly on the metal required to be gilt, to which it attaches itself closely, in consequence of the

attraction of the metals for each other: in this state the whole is submitted to the action of a moderate heat, which causes the mercury to pass off in a state of vapour, and leaves the gold permanently attached to the other metal. Mercury has a very strong affinity for gold, and may be seen to fix itself on and change the colour of this metal, even through the skin and apparel of those persons who have taken it to any extent; this is a very common case in the West Indies, where so much calomel is used. Mercury combines with the metals, forming amalgams: one of tin, zinc, and mercury is the best compound in use, to be laid on the cushion of the electrical machine, to excite its action.

Copper is of important use in many of the arts of life; and it is abundantly found in some parts of England and Wales, as well as many other parts of the world. It is unnecessary to describe the external appearance of this metal. It is more ductile than any of the metals except gold; it forms various salts, &c. in combination with the acids and other simple substances, and is of great utility as an alloy to other metals, and also in forming various utensils, in sheathing the bottoms of ships, &c. It is found native in some parts of the world; but the chief form under which it occurs in England is that of copper pyrites, as it is called, which is copper combined with sulphur.

It is in this state that it is found in the Cornish mines; and it is a remarkable illustration of the beneficial results of chemical science, that what now forms the principal object of search in those mines was formerly thrown aside as useless, the mines being worked merely in search of tin. And, in fact, the rubbish or refuse is now searched for those very copper pyrites which were considered as valueless by the old miners, and in many cases the production of this second working is infinitely more valuable than the first could have been.

The salts formed by copper and the acids are of great variety and utility. Most of these salts are occasionally found in a native state; but those employed in the arts are usually formed by artificial means. Many of the most beautiful mineral colours, particularly the greens, are formed by copper: the beautiful mineral production called malachite is a carbonate of copper; and *brass* is an artificial metal, formed by a mixture of copper and zinc.

We have next to speak of *iron*, which is a metal of vast importance, and of almost universal occurrence, being found in all parts of the world, and in almost every natural production of it, animal and vegetable, as well as mineral. Iron is incomparably the most useful of all the metals, or perhaps of any other substance whatever; and it

should therefore, properly speaking, be regarded as the most valuable. It is also the most abundant of any of the metals. It is found native, in very large masses; and many of the mountains of our earth are formed entirely of iron ore. Perhaps the most important, and certainly the most curious property of iron, is its capability of being rendered magnetic. It is perhaps superfluous for me to state, even to the youngest of my hearers, that it is in virtue of this quality of iron that we are enabled to form those instruments which direct the course of the mariner to every part of the globe, and without which an intercourse with distant nations would be impracticable. The magnetic property is very easily communicated to iron, either by suspending it for a certain time in a particular position, by the friction of another piece of iron already possessing that property, or by the natural magnet. It may also be communicated by electricity and galvanism, and by percussion.

I have said that iron is found in a native state. This fact has been doubted, however, by some chemists, who have suspected that the native iron hitherto found has had a meteoric origin, since it exactly resembles that which is known to have had that origin. The fact of these masses being invariably found insulated, and at a great distance from any bed or mountain of iron ore, favours

this supposition. The celebrated La Place, and also Dr. Hutton, have supposed that the masses of this kind hitherto found, have been projected hither from a volcano in the moon. There is a mass of native iron in the Academy of Sciences at St. Petersburg, which weighs twelve hundred pounds. Iron, when in a state of purity, is soft and ductile, but is almost infusible. It possesses, however, the property of welding, as it is called; that is, a portion of it is capable of forming a perfect union with another portion, by bringing the two into close contact, at a white heat, and hammering them in that state: no other metal except platina possesses this property. By a union with the acids and other substances, iron forms various compounds, which are of great and universal use: the chief of these is *steel*, which is iron with a small portion of pure carbon united with it. This union gives to the metal an hardness, and consequently renders it capable of receiving a polish which no other metal will. The formation of steel is perfectly simple: nothing more is required than to heat the iron, in contact with carbon, in the form of charcoal; at a certain temperature the two substances unite, and the product is steel. The hardness, and consequent value of the steel, depends in a great measure on the degree of heat employed. Our time will not admit of my noticing at any length the various oxides, salts, &c.

that are formed by this metal; but they are of the greatest importance in the fine arts, in dyeing, in medicine, &c. and we may probably have occasion to notice some of them more particularly hereafter.

With respect to the remaining metals, it will be impossible, and indeed unnecessary for me to do more than take a slight general view of them. Besides the metals which I have just described, there are only four others that are malleable; and as the malleability of the metals is the chief source of their utility and importance, it is obvious that those which do not possess this quality, call for a very inferior degree of attention. The four other malleable metals are *lead*, *tin*, *zinc*, and *nickel*. *Lead* is the softest of all the metals, and is of much utility on this account. It also forms compounds with the acids, &c. which are of use in the arts; but which are extremely deleterious, if not judiciously applied.

Tin is a metal also in great use in domestic economy, and also in the arts. It is much employed by dyers, calico-printers, &c. when combined with the acids, &c. Tin and lead are both found in abundance in this country.

Nickel is a metal which has not hitherto received the attention that it seems to deserve. When in a state of purity, it is exceedingly mal-

leable, and has very little attraction for oxygen: which two qualities alone would render it of great use for many purposes. But it is also said to possess the power of being attracted by the loadstone, even more strongly than iron is, and also to attract iron in the same manner that the loadstone does. The salts, &c. of this metal are various in their nature and qualities, and have hitherto been chiefly used in communicating colours to various substances, such as glass, china, &c.

Zinc, the last of the malleable metals, is the most combustible of them all, but the least ductile. When beaten into thin leaves, it will burn in a common taper. Indeed its affinity for oxygen (to which it owes its combustibility) is so great, that it will decompose water at the common temperature. Some time ago, some manufacturers of Sheffield obtained a patent for rendering zinc perfectly malleable; and, supposing this to be practicable without difficulty, zinc might undoubtedly be applied to most important uses, since it is the most abundant metal in nature except iron. Perhaps the most important use to which zinc is applied at present, is in the formation of our galvanic batteries. Its oxides and salts are also used with advantage, in medicine and in the arts. In the notice of copper, I stated that brass consists of a union of that metal with zinc.

The other metals, being either highly brittle, or nearly infusible, or both, are of scarcely any use in their metallic state: I shall therefore pass them over, by observing that they nearly all form oxides and salts, by a union with oxygen and the acids; and that these compounds are all of them more or less of use in the arts, in medicine, &c. With respect to *manganese*, *cobalt*, *antimony*, *arsenic*, *tellurium*, *tungsten*, *molybdenum*, *uranium*, *chromium*, *titanium*, *columbium*, and *zantalium*, I repeat, all these metals are brittle, and the greater part of them are nearly infusible. When I say infusible, I mean by our common blast furnaces; but they all give way to the ox-hydrogen blow-pipe, and some of them burn with very beautiful colours and scintillizations; they will be noticed in this respect when speaking of this instrument.

Slight as the sketch has been that I have given of the metals, the time allotted for each of these lectures will compel me to compress my notice of the *earths* into a still narrower compass. And, in fact, the nature of our present course of study does not require, or even admit, of any very detailed account of these bodies. Until very lately, the earths have been considered as simple bodies, no means having been found to decompose them.

Since the discoveries of Sir Humphry Davy, with respect to the composition of the alkalies

(which discoveries I shall notice in my next lecture, when treating of those substances), experiments have been instituted, both by him and other distinguished philosophers, which lead us to more than suspect that the earths are, like the alkalies, metallic oxides. As, however, we are not in possession of a sufficient number of facts to place this theory beyond a doubt, I shall merely speak of the earths as we find them, without considering them either as simple or compound; neither shall I divide them, as is sometimes done, into earths simply, and alkaline earths, since I see no specific good that can result from this division; and since, moreover, it involves an inconsistency: for the alkalies, as I have just stated, are now positively proved to be metallic oxides. I may state, however, that the only important difference between what have been called the alkaline earths and the others, is, that the former have afforded more satisfactory proofs of being metallic oxides than the latter have. The four earths I am now alluding to is *baryta*, *strontia*, *lime* and *magnesia*. The earths are none of them more than five times heavier than water; and all, except the four I have named, are inodorous and tasteless, and until lately they were considered as incombustible; but, like all other solid substances, they now yield to the united energies of oxygen and hydrogen gases.

I consider *silica*, or silex, to be by far the most interesting and important of the earths, and I shall pay most attention to it accordingly. Silex exists in nature in a state of almost perfect purity in the rock-crystal; and it is found also in most of the precious stones. It also forms, in a less pure state, a vast proportion of the solid bulk of our earth. The chief use to which it is applied in the present day is in the formation of that beautiful material glass, of which it forms the principal ingredient. It is rendered fluid by the admixture of a portion of alkaline matter; and when in this state, it is formed into the various objects which we see in constant use. Glass owes its extreme utility, both in domestic economy and in the arts, to another peculiar property of silex—namely, its capability of resisting the action of all the acids, except one, the fluoric. If it were not for this property, which the silex communicates to glass, chemistry would be deficient in the means of performing a vast number of her most beautiful and important experiments. Silex also plays an important part in the formation of all earthenware, porcelain, imitation gems, &c. Finally, it constitutes the chief part of that curious mineral substance called amianthus, which may be divided into threads, and woven into a species of cloth, which is indestructible by fire. The ancients used to wrap the bodies of their dead in this cloth,

in order to preserve them from mixing with the ashes of the funeral pile on which it was the custom to burn them; and, in examining the ruins of Herculaneum and Pompeii, several urns have been found, containing bones wrapped in this material, which seems to be in as perfect a state now as when it was formed two thousand years ago.

I must now close this lecture by doing little more than enumerating the remaining earths; but I shall have occasion to examine some of them hereafter. The four other earths are *alumine*, *glucine*, *zircone* and *yttria;* and they resemble each other as well in the general characters I have noted before, as in their properties of dissolving in the acids to form salts, &c.

LECTURE XI.

ON THE ACIDS AND ALKALIES.

In the present lecture I propose to examine those most interesting and important classes of bodies, *the acids* and *the alkalies*. Those properties which are peculiar to *the acids* may be thus stated: they have a taste which is in common language denominated sourness, and this taste differs in the different acids, and obtains in a greater or less degree, as the solution of the acids in question are more or less concentrated. When they are at all strong, this taste, in many of the acids, is so pungent as not to be borne by the tongue. The acids have also the property of changing certain colours, to others of a totally different kind; but, in particular, they change all the vegetable blues to reds. The acids have also the quality of uniting chemically with the metals, with the alkalies, and with the earths, to form peculiar bodies, of totally different qualities from those possessed by either of their constituent parts, and which bodies can be procured in no

other way than by this union. It was formerly, and until very lately, considered as an incontrovertible law of chemical science, that oxygen was the principle of acidity, and that by its means alone, bodies could be formed possessing the foregoing qualities; and its name was constructed on this understanding, oxygen meaning, the giver or causer of acidity. Further progress in science has, however, proved to us that there are other elementary substances capable of producing acids and acidity; and moreover that there are bodies produced by one or other of these elements, which do not combine all the qualities I have just enumerated. For instance, prussic acid neither reddens vegetable blues, nor is it sour to the taste; yet it combines with the metals, earths, &c. so as to form saline bodies analagous to those produced by the other acids. And, on the other hand, there are bodies which exhibit some of the properties of acids, which yet do not claim to rank among them; sulphuretted hydrogen gas, for example, reddens the vegetable blues, and combines with the alkalies and earths.

But to go further into these minute points of the science is more than the nature of our plan will admit. The principal point on which I shall have to enlarge, in this part of my subject, is that quality of the acids in virtue of which they form a union with nearly all the bodies which I have

named: the metallic oxides, the alkalies, and the earths; and by this union lose their own specific qualities, and destroy those of the bodies with which they combine, producing an entirely new class of bodies, which are termed salts. By this statement it will at once be seen that, whenever we speak of a salt, or a saline body, we mean a chemical compound composed of some one of the acids with some one of either the metallic oxides, the alkalies, or the earths; and the names of the salts are at present so constructed, that they necessarily indicate which of the acids, and which of the metals, alkalies, or earths, have united together to form the compound in question. Nay, more, the names of the salts, according to the new nomenclature, not only indicate the bodies of which the salt has been composed, but the relative proportions which obtain in the composition: for it must here be observed, that the substances of which we are now treating are capable of uniting with each other in more than one proportion, and consequently of forming more than one kind of compound, which compound still retains the name of a salt, on account of its component parts being those which I have named; but its qualities depend altogether on the proportions in which those component parts are mixed. As an example of what I mean, both with respect to the names of these bodies, and their

qualities, I may state, first, that the genuine name of the salts to be described, or the name of the class, is taken from the acid which goes to form them; secondly, that the name of any particular salt which forms one of that class is taken from the base, that is to say, from the metal, alkali, or earth; and lastly, that the termination of the generic name indicates the proportion of acidifying principle. Thus the salts formed by the acids of sulphur are called sulph*ates* or sulph*ites*, according as the said acid contains one or two portions of oxygen. This rule is applicable to all those salts which are called neutral; that is to say, those in which neither the acid or the base predominate. But there is a further class of salts into which there enters a third, and even a fourth proportion of oxygen, or other acidifying principle, and these salts have their names lengthened by the Latin prefix *super*. For example, potash is capable of combining with three proportions of sulphuric acid, forming three distinct compounds; that containing the first proportion is termed the sulph*ite* of potash, that containing the second is termed the sulph*ate* of potash; and that containing the third is termed the *super-sulphate* of potash. A very little practice will render the student perfectly familiar with the principle of this mode of naming the products of chemistry, and will convince him of its great utility and im-

portance. Indeed, without it the very best memory would be unable to retain a knowledge of the qualities and component parts and proportions of that immensely extended class of bodies to which our attention has just now been incidentally directed; I mean the salts formed by a union between the acids, and the metals, alkalies, and earths.

Returning now to the acids, I shall examine them individually; premising (as I am repeatedly obliged to do), that my limits compel me to make this examination extremely short, and I fear unsatisfactory. But, to those who find it so, I can only refer to the numerous extensive and excellent works which we at present possess on chemical science, but which it would be useless to name here, because the particular work which I should recommend would depend entirely on the nature and extent of the knowledge desired to be derived from it.

As chemistry is acquainted with between thirty or forty different acids, it will be evident that I can enter into an examination of but very few of them individually. I shall therefore make choice of those which present the most striking qualities, and are subservient to the most important uses; and these will be chiefly those acids which belong to what is called the first class; namely, those which are found to be composed of but two principles or elements: the second class of acids

(which are the most numerous, but by far the least important,) consisting of three or more elements. I shall begin with *carbonic acid*, which consists of carbon and oxygen. This acid is available for the purposes of observation and experiment in the form of a gas only, and in this form it is invisible; it is destructive to animal life if taken into the lungs, and is much heavier than common air. It has a slight attraction for water, which may consequently be made to take up about three times its bulk of it, in which state the water acquires an acidulous taste, and the use of it as a beverage is very beneficial under certain circumstances. What is sold as soda-water ought to be simply pure water impregnated with this gas; but I am afraid this is very seldom the case. Carbonic acid is a compound of two to one—two of oxygen to one of carbon. It was discovered by Dr. Priestley, who first observed it as given out by fermenting liquors, he accidentally introduced a lighted candle into the mouth of an ale-barrel when in a state of fermentation, and found the taper extinguished by some peculiar property of the air which the vessel contained. This was a sufficient hint for him to institute an inquiry into the cause of the phenomenon in question, and the result of that inquiry was the discovery of carbonic acid gas, which he called *dephlogisticated air*. This name was changed after-

wards to *fixed air*, because it is found fixed in almost all vegetable substances. It is so very heavy, that it may be poured like water from one vessel to another. It is procured for experiment from chalk, marble, &c. All that is necessary to be done in order to obtain it, is to pour dilute acid of any kind (say dilute muriatic acid) on either of these substances in a retort, the gas will escape in large quantities, and may be received over water in the usual way. It extinguishes flame, and is not in any way combustible, nor will it support combustion. Introduce a lighted taper into it, and it will instantly be extinguished; place a lighted taper at the bottom of a glass vessel, and pour as you would water the gas from another vessel, the taper will be extinguished in consequence of the weight of the gas causing it to flow from one to the other without being dissipated. In consequence of its great comparative weight, it may be collected without the aid of the pneumatic trough, by simply allowing it to fall from the beak of the retort into a glass vessel. The atmospheric air this vessel contains will be driven out, and the carbonic acid gas will occupy its place. It has a strong affinity for lime, which takes it from the atmosphere in ordinary cases, whenever exposed to it. Lime-water, by exposure to the air, becomes soon covered with a crust, which is a carbonate of lime.

Lime water is used as a test for this acid when uncombined. If it be agitated in contact with carbonic acid gas, it very soon becomes milky in appearance; this is caused by the carbonate of lime which is formed, and which is insoluble in water, and will fall to the bottom of the vessel if suffered to remain at rest for any length of time. It is as fatal to animal life when taken into the lungs as it is to combustion. It is found in wells, and deep excavations of the earth; particularly if there is not a free draft or access of the atmosphere. Many caverns, particularly one in Italy offers an instance of the natural production of carbonic acid, and also of its specific gravity; a dog will fall instantly dead on entering this cave, because he is not sufficiently high to breathe above the stratum of this air; but a man suffers no inconvenience on entering in the erect position, because he breathes above the stratum of gas, and consequently in the pure atmosphere.

When wells are opened that have been a long time covered, this gas is frequently found in them, and many fatal accidents have attended an incautious descent, in consequence of its presence.

As this air extinguishes flame, a very easy and certain method is always at hand of detecting its presence. It is only necessary to lower a lighted candle previous to any person attempting to descend

into the suspected spot; if it burns, there is no fear of the presence of carbonic acid gas.

This gas is given out from the lungs in the breath of animals. This may be proved by blowing by means of a quill or glass tube through lime water; it will soon become turbid, and thereby indicate the presence of carbonate of lime. A little muriatic acid instantly renders these turbid mixtures perfectly transparent, by uniting with the lime, forming thereby a muriatic of lime, which is soluble; it disengages the carbonic acid gas, which always escapes, as it is not absorbable by water in any notable quantities, and can only be kept in union with it by means of pressure. Although carbonic acid is fatal to animal life when taken into the lungs, yet it is grateful and stimulating when taken into the stomach. It is an antiseptic, and prevents putridity; it is of great advantage in the hands of the physician on this account.

Saline draughts owe their salubrity to the disengagement of this gas in large quantities, when their compound parts are first mixed. They are generally formed of a carbonate of soda, or potassa, and lemon or other acid. The acid employed unites with the soda or potassa, and liberates the carbonic acid gas. It has a weak affinity for these alkalies, and therefore may be displaced by almost any other acid; although this acid is never known in a solid form when uncombined, yet, when united

to lime, it becomes exceedingly hard, as in the form of common marble, &c.

Many natural waters (mineral waters as they are called) are found to be strongly impregnated with this gas, and they owe their salubrity chiefly to the properties which it communicates to them.

The salts formed by the combination of this acid with the metals of alkali, and the earths, are called carbonates, carbonites, and sub or supercarbonates, according to the proportion, in which the acid obtains; and some of these compounds exist in vast abundance, forming many of the solid and mountainous parts of our globe. Marble, chalk, and the various kinds of lime-stone, are all nearly pure carbonates of lime.

Sulphuric acid, when first formed, exists in an aeriform state; it cannot be applied to any practical purposes in this state, and is therefore usually combined with a portion of water, for which it has a strong attraction. In this form it is a ponderous fluid, colourless, and destitute of smell, but capable of acting in the most violent manner on various substances. It is procured by burning sulphur and nitre in oxygen gas, or in contact with some substance which contains a considerable portion of the latter element; it is a compound of three to one: three of oxygen to one of sulphur.

It is applicable to various useful purposes in the

arts, &c. in its state of an acid; and in combination with the metallic oxides, the alkalies, and the earths, it forms those salts called sulphates.

There is another acid of sulphur, which should perhaps have been mentioned first, since it is that which is formed by the first proportion of oxygen with the sulphur. This is called the *sulphurous acid;* it is a compound of two to one, two oxygen to one of sulphur.

Its acid properties are not near so strong as those of the sulphuric acid; like that it is in the form of a vapour, when uncondensed by water, and instead of reddening the vegetable blues, it discharges their colour altogether, rendering them white. This property makes it of great use to the dyer and bleacher; and it is also used in various ways, to change and modify the different colours, and their subordinate hues.

It is this acid which is discharged in vast quantities from the mouths of volcanoes, and which possesses a highly pungent smell, and produces a suffocating effect. Pliny, the naturalist, was suffocated by this gas, during that eruption of Vesuvius which destroyed the cities of Pompeii, Herculaneum, &c. Sulphurous acid gas is heavier than common air; and it is said to have been administered with success as a medicine, in certain affections of the lungs.

Nitric acid consists of precisely the same mate-

rials which form the air we breathe, the proportions alone being different. Thus we find that different proportions of the same materials are capable of producing an air which is health and balm to our nature, and without which we could not exist for a moment; and another air which is so corrosive and destructive, that a very small portion of it taken into the body would cause almost immediate death. This is one of the most striking examples we are able to adduce of the wonderful difference of quality in a body produced by the difference of proportion alone in its consituent parts. It is said to be a compound of five to two, five of oxygen to two of nitrogen. Nitric acid, like the foregoing ones, has a strong affinity for water, and in the fluid state it is combined with that substance; but when consisting simply of its elements (of nitrogen and oxygen merely), it exists, like most of the other acids, only in the form of a gas, or perhaps it would be more consistent with modern philosophical doctrines to say, of this as well as of the others, that when combined with caloric, or the matter of heat only, they exist as aeriform fluids; but when combined with water, and thus condensed and separated from their caloric, they take the form of tangible and ponderous liquids. Nitric acid, like several of the others, is destructive to the composition of all animal bodies; it unites with nearly

all the metals, taking up and dissolving some of them, so that they totally disappear in it; and with various other substances it unites, and forms the salts called nitrates, many of which are of great value in medicine, and in the arts.

The nitrous acid, the next we shall notice, is a specific body containing a definite proportion of oxygen; a less proportion than the nitric acid. It is a compound of two to one, two of oxygen to one of nitrogen. It combines with water, and forms the *aquafortis* of the shops. It stains the skin yellow, emits dense fumes when exposed to the atmosphere, and is of a red or rather yellow colour.

The only other acid we shall be enabled to discribe at present is the *muriatic*. It is a compound of one to one, one of hydrogen to one of chlorine. Its base has been the subject of much discussion, and has occupied the attention of many of our most eminent chemists, and even now the question remains, in the opinion of some, in an undecided state. I shall, therefore, merely allude to the qualities, &c. of this acid; referring those who would become acquainted with the various discussions on the subject, to those philosophical journals, and other works, in which they have appeared.

Muriatic acid, like those I have already described, exists only in the form of a gas; but it has so strong an attraction for water, that it in-

stantly combines with it on their coming in contact, and forms the liquid muriatic acid of commerce, or what used to be, and still is, in common language, called *spirits of salts;* on account of the chief source of its production being the common salt of our tables. This acid, in combination with other substances, forms a great variety of useful salts, which are called *muriates;* and in combination with nitric acid, it forms the only known acid substance which has any effect on gold. By means of this mixture, however, which was known to the ancients under the name of aqua regia, gold may be perfectly dissolved, and held in solution, in an invisible state. It may be formed by uniting hydrogen and chlorine together in the above proportions; the only product of these will be muriatic acid.

It will not be proper to do more than mention in this place what has till lately been called *oxy-muriatic acid*, because that body is now universally allowed to be neither more nor less than chlorine, which I examined in a former lecture. This substance, in a state of gas, was for some time considered as an acid, because it changed the vegetable colours in some instances, and discharged them in others; but this was found to be occasioned in every instance by the presence of water, which imparted hydrogen to

the chlorine, and oxygen to the colouring matter, and thus generated the specific muriatic acid and discharged colour. The most delicate test of the acids, namely, litmus paper, if placed in contact with chlorine gas, remains unchanged, provided both the gas and the paper be in a perfectly dry state.

The remaining acids, of which there are no less than three or four and twenty, are chiefly compounded of three, and sometimes more principles, which are usually carbon, hydrogen, and oxygen, and sometimes nitrogen. Their characters are much less decided, and their uses much less various and important, than are those of the other acids which I have examined in detail. Some of them, particularly the *prussic*, are of much use as chemical tests to detect the presence of certain elements. Others, such as the *citric*, *tartaric*, *gallic*, *oxalic*, &c. are of use in domestic economy —in medicine—in discharging, changing, or communicating colours, &c. &c.; and the whole form a variety of specific salts, most of which are applied to some uses, and may probably hereafter be rendered still more valuable.

I now proceed to give a brief sketch of those particular bodies called *the alkalies*. These bodies in some measure partake of the nature of the earths, and were for a long time considered as simple substances; Lavoisier, however, stated

them to be metallic oxides so early as the year 1786, although no known agency was capable of separating their constituent elements. Sir Humphrey Davy has now demonstrated that two, at least, of these bodies are oxides of peculiar metals; but as the attraction of these metals for oxygen is so strong that they cannot fairly be considered to exist in a natural state separated from that body; and as, in the unions which they form with it, they present peculiar qualities; I have thought it better to treat of those unions in this place, rather than to range their bases among the other metals.

Speaking of the alkalies, then, as chemical compounds (and in a pure state they are not to be procured except by that agency), their qualities are these: they have a peculiar taste, which should perhaps be called alkaline, for it belongs exclusively to these bodies; they exercise a peculiar caustic action on the skin, and reduce some animal substances to a uniform, and in many cases transparent mass, or jelly; they render oil and water capable of uniting together, and forming one body; and they change the vegetable blues to greens. There are three alkalies; two of which are termed *fixed*, and the third *volatile*. The two first, both in commerce and in science, are called potash or *potassa*, and *soda*, and the last *ammonia*. The uses of these bodies in their alkaline form

(and particularly of the two first) are various and important. They offer the sole means of forming that universally useful material, soap: which consists of one or other of the fixed alkalies, united with the fat or oily parts of animal matter; they form the solvent by means of which silex is converted into glass; and they are applied in various ways in the manufacture of colours, in bleaching, dyeing, &c. Finally, they form saline bodies, which are of great use in medicine.

With respect to the composition of the alkalies, I have just stated to you that, after having for years resisted all attempts at decomposing them, Sir Humphrey Davy, by means of a powerful galvanic battery, succeeded in effecting this, and in exhibiting their elements in a separate state.

Setting out on the grand and universal principle (now fully established), that all supporters of combustion are attracted to the positive pole of the galvanic battery, and all combustible bodies to the negative pole; and conceiving beforehand the probability of the fixed alkalies being formed of oxygen and a combustible base; he determined to experiment upon them in conformity with this view of the subject. His first experiments, though highly interesting in their results, were not satisfactory. He subjected potassa to the influence of a battery of two thousand pairs of six-inch plates, and immediately, at the negative end, there was

evidently a development of combustible matter, which, however, was consumed and disappeared as soon as given forth. This arose from the presence of atmospheric air, and probably also from the water with which the potassa was united; for both potassa and soda are seldom found in a perfectly dry state. After numerous variations in the manner of performing the experiments, so as to obviate as much as possible the difficulties attending them, Sir Humphrey Davy at length perfectly succeeded in exhibiting and even collecting the two results of this striking and novel decomposition. His plan was this: in a small cup or plate of platina (which, as I mentioned to you in my last lecture, is capable of resisting an intense degree of heat), he placed a small portion of pure potassa; he then connected the bottom of the platina cup with the negative end of the galvanic battery, and completed the communication between the two poles by bringing the wire connected with the positive end into contact with the piece of potassa. At the instant of completing the communication, a violent effervescence took place at the upper surface of the potassa, which was connected with the positive end, and which action was caused, as he ascertained, by the evolution of pure oxygen gas. He had thus evidently procured one of the elements of the potassa, which was undergoing decomposition. At the

same instant that this process was going on at the positive wire, the negative wire was developing no gaseous matter at all, but a peculiar substance exhibiting the appearance of brilliant metallic globules, exactly resembling quicksilver. These, when suffered to remain in contact with the air for a very few instants, either burnt spontaneously, or were converted into a white powder. Here was evidently presented the other constituent or element of the compound under examination. Still proceeding on the principle that this new production, being attracted to the negative pole of the battery, was a simple combustible, and the base of the compound; he contrived, immediately on its appearance and formation, to receive it into naptha, a peculiar substance to be described hereafter; this had the desired effect, and he was able to collect in this manner solid globules of the body which I have described, and which in that state exhibited all the properties of a metal. The experiment was thus far, and, as it respected the analysis of the body under examination, quite satisfactory: but in order to render it still more complete, and to place beyond the possibility of a cavil or doubt the principle it was intended to illustrate, Sir Humphrey Davy now exposed the metal, thus procured from pure potassa, to the action of pure oxygen gas, and the result was a reproduction of pure potassa.

In treating the other alkali, *soda*, in a similar manner, exactly similar results were produced; and in exposing the globules of metal thus obtained, to the action of oxygen gas, if the said globules were obtained from potassa, potassa was the alkali reproduced; and if they were procured by decomposing soda, soda was the result.

The metal from potassa is called *potassium:* that from soda, *sodium.*

At the time that Sir H. Davy was decomposing the alkalies by the great battery, at the Royal Institution, M. Gay Lussac and Tenard succeeded in forming potassium, by a very different and less expensive method, as well as in greater quantities. This method is highly valuable, as it furnishes the potassium with such facility, and with so little comparative expense, that chemists may obtain it in sufficient quantities for their purposes; it forms one of the most valuable chemical agents we possess. The French method, is to pass potassa through a bent gun barrel or other iron tube, containing iron wire, &c. kept at a temperature very nearly equal to that necessary for the fusion of the metal; at this elevation of temperature the iron attracts oxygen with so much avidity, that it actually takes it from the potassa, and thus decomposes it. The other element of potassa (namely, potassium) sublimes in the first instance, and rises in the tube till it reaches a part which is kept cold by water

or ice, where it condenses on the inner surface; and from whence it is removed after the operation by cutting it off with a knife or other instrument. The minutiæ of the operation may be seen in any of the scientific journals. Potassium has so strong an affinity for oxygen, that it will decompose many substances in which this element obtains, and where it is held by a strong affinity; water, for instance, is decomposed by simply bringing it in contact with potassium, which latter spontaneously takes fire from the rapidity of the action, and, combining with the oxygen of the water, forms potassa. On account of the strong affinity of potassium for oxygen, it is of the greatest value for various chemical purposes.

It only remains to notice the *volatile alkali*, which is called *ammonia*. Ammonia, in a state of purity, exists in the form of a gas alone, which has a pungent and disagreeable smell; it extinguishes flame and animal life, and is lighter than common air. It is said to be composed of nitrogen and hydrogen, in the proportions of three to one, three of hydrogen to one of nitrogen: there is, however, some foundation for the belief which some chemists hold, that this is not its composition.

Ammonia is of considerable use in medicine and the arts, when combined with other bodies, to

form salts. Many of these are highly volatile: the common smelling salts is one of them—carbonate of ammonia—this alkali is also of great use to the dyers, colour-makers, &c.

LECTURE XII.

NATURAL PHENOMENA.—CONCLUSION.

THE branch of chemical science which I have named in the syllabus, as the subject of this concluding lecture, would afford ample materials for a whole volume, instead of the few pages which our limited time permits me to devote to it: so that any thing like an adequate and satisfactory general development of it, is of course more than I shall attempt. The utmost I can pretend to do, will be to take up a few of the most striking and important points that present themselves; and by my examination and treatment of these, endeavour to lead your attention to this branch of study, and to impress upon you a sense of the infinite importance of it, whether we regard it in the light of a philosophical speculation, or with a view to its practical results. Neither must I conceal from you, and still less from myself, the extreme difficulty of that part of the study of chemistry which is to occupy our attention this evening. I propose to consider a few of the grand phenomena of

nature, as they are connected with and dependent on chemical causes; and these, however striking and imposing they may be in their appearance and results, are necessarily, and indeed on that very account, so far removed from the immediate sphere of our actual examination, that we are compelled to experiment upon them by analogy, or by proxy, if I may so express myself. In examining the objects and effects that occur immediately around us on the face of our earth, we can make them subject to our bidding, and obedient to our will; we can bind them down before us, and forbid them to leave our presence, till we have wrung from them a confession of all that we desire to learn respecting them. They cannot escape, or deceive, or overpower us. Reasoning and experience have enabled us to acquire an absolute mastery over them; and if we do but proceed simply and philosophically in our work, the truth is sure to be at once the result and the reward of our labours.

But in examining the grand, the distant, the intangible, the invisible operations of nature, we find ourselves in a widely different situation. Instead of commanding, we are compelled to obey: instead of calling forth the truth at once, by a touch of our instruments, or a trial of our never-failing tests and agents, we are compelled to wait, and watch, and listen, and calculate, and prove,

and re-prove, and can scarcely be satisfied that we have arrived at a right conclusion at last.

This being the case, I do not doubt that I shall meet with that indulgence on this occasion which I have never failed to experience here, even when I have had less need of it than I feel that I am likely to have this evening. Hitherto I have been enabled to occupy your attention, and direct your study to facts; and if I have not made those facts obvious to your perceptions, and have not satisfactorily developed their causes, it has been fairly attributable to my own deficiencies. But now I am about to call your attention chiefly to appearances, and to offer to your notice chiefly conjectures and guesses; and if these should fail of satisfying and convincing you, I shall not have any just ground for either surprise or regret, since I am far from being satisfied or convinced about them myself. But still I shall not affect, because I do not feel any reluctance in offering these conjectures to your notice, for I have seen enough of experimental philosophy in the hands of others, and have had enough practice in it myself, to know that the most brilliant discoveries, and the most important facts and theories, not only may arise occasionally out of happy guesses, but that the most brilliant of these which we boast the possession of, have actually arisen out of these, rather than out of a direct course of study and expe-

riment undertaken for the purpose of eliciting them. To bring theories to any thing like a condition of practical truth and utility, regular experiments, adapted and contrived for this express purpose, are frequently indispensable; but the origin of them may very frequently be traced to mere accident, and those experiments which have led to the establishment of them have been still more often the result of shrewd conjectures or of happy guesses.

I conceive that in moral philosophy we have no right to proceed on any grounds but those of fact and experience on the one hand, or of revelation on the other: for where, as in this case, there is no beginning to our conjectures, there is no chance of their arriving at any end. If we begin to guess at all as to the nature of moral causes, we may guess about them as much as we please, for there is no reason why we should ever stop. And, in fact, about that which we actually know nothing, we never can by any possibility know any thing except through the interpretation and revelation of a superior power; so that guesses and conjectures, when applied to moral agents and attributes, are at best nugatory, and for the most part presumptuous and mischievous. But with regard to physical philosophy, the case is altogether different: here conjecture is a legitimate source of knowledge, an authorized agent in not only stimu-

lating us to seek, but leading us to find those fountains of information, from which truth alone can be expected to proceed. Frequently nothing is needed but the merest hint, to set our faculties at work in a direction which leads us to what we seek; and if it does not lead to that, it frequently and almost certainly leads to something, which may turn out to be even more valuable and desirable than the object of our immediate search.

I shall commence with an examination of the *effects of light in natural phenomena*, as connected with the science of chemistry. I have noticed light in my previous lectures, but only with a direct reference to the subject then immediately before us; I shall now notice it in its more important character, viz. as connected with and influencing the changes which take place in natural objects; for light, as well as heat, I have no doubt, is a modification of electricity, and may be regarded as equally important in the economy of nature.

There are many most curious and interesting facts connected with light, which have hitherto been examined with but little accuracy, and others that seem to me to have been disregarded altogether. It is well known that light is essential to the perfect and healthful vegetation of *plants*, and that they almost entirely lose their colour when kept from the access of it. But the true reason for this seems to have been very little

examined into, and still less understood. For my own part, I have little doubt that light owes its power of assisting in vegetation (and particularly of communicating those various delightful tints and colours which are conspicuous in the vegetable kingdom), to its oxidizing or chemical power. It is well known that some of the metals enter into the composition of plants; and I conceive that their various colours are derived from various proportions and modifications of these metallic oxides, undergoing various changes, which changes are occasioned simply by their contact with light on the surface of the plant. It is there only that vegetables meet with that agent, which communicates to them all the beautiful hues which are, in many instances, the sole value which they are known to possess, or were probably intended to possess. We may be satisfied that there are many objects in the world, which were placed there chiefly with a view to the immediate gratification of sentient beings, and to some, flowers may be regarded as the principal and most valuable of these: the quality of effecting this end they owe to the agency of light; and, it seems to me, in the manner that I have just stated.

It does not seem necessary that I should here enter into an examination of the question, which relates to what particular part of the prismatic spectrum this chemical quality belongs—or how it is that that

part which is immediately beyond the visible part of the ray of light, should possess still more powerful qualities in this respect than any other: for the prismatic spectrum itself is but an effect of art, the qualities and properties which belong to light in its common character as an agent, in producing the phenomena of external nature, being so united together when they are acting in this character, that the inquiry would be altogether irrelevant. A ray of light, divided into many different parts by the art of man, is no doubt a most curious object of examination; but a ray of light acting on the vegetable world, or in any other character except in that of forming the rainbow, is a homogeneous and individual thing, and to be regarded as such.

I may here state that it is during the day-time alone, and during the presence of light, that plants absorb the combustible portion of their matter; it is therefore fair to conclude, that light plays an important part in the formation of this combustible portion, since it cannot be formed in the absence of it. During the night, plants give out nitrogen, but they do not absorb or take in carbon, which is a component part of their necessary food, probably because they cannot receive it unless it be modified by the agency of light; which seems to be one of their "necessaries of life." There can be little doubt that, during the night-time,

plants do nothing more than concoct, or as it were digest, that portion of food which they have taken in during the day, giving out that portion which is not nutritious to them; namely, the nitrogen.

I shall venture to carry this conjecture respecting the agency of light somewhat farther, and state, that I conceive even the healthful condition *of animal life* (as well as vegetable) to be in some measure dependent on its action and effects.

The blood in animals contains iron and other metallic oxides, which not only occasion its particular colour, but determines its fitness for regulating the functions and renovating the powers of the system. We observe invariably, that persons who are confined and excluded from light become first pale and sallow, and finally sickly and deceased.

Perhaps this may arise chiefly from the imperfect oxidation of the blood, occasioned by the absence of light, added to the consequent call on some other agency to supply the deficiency; which call necessarily deprives some other portion of the system of its needful action or support. Certain organs, not expressly adapted for that purpose, are called upon to assist in furnishing this necessary change, and are therefore compelled, in the mean time, to forego some of their own peculiar duties, and the healthful balance of the system is thus disturbed. These peculiar effects in the animal sys-

tem, such as loss of colour, &c. are in many cases produced entirely from want of light, and not from confinement which may be supposed to occasion them, as facts testify which every day occur.

Light influences colour more strikingly in the *plumage of birds*, than, perhaps, in the external appearance of any other class of animals. Those birds which are natives of the torrid zone are generally of an extremely rich and beautiful plumage; while those in the frigid zone are principally whiter. It is worth while to remark here, the manner in which this peculiar law of nature is made subservient to the welfare of the animal. Coloured bodies are all better conductors of heat than white, therefore animals clothed in white under the frigid zone are better enabled to bear the severe cold, to which they are liable in those regions, from the natural heat of the body being less easily conducted away. Partridges, hares, &c. are perfectly white in Lapland. The colour of *fish*, also, prove the influence of light: for we invariably find that the backs, or upper parts, which are exposed to the direct rays of light, are dark when compared with the under parts, which are in a great measure excluded from it.

The Indian finds his way through the uncultivated forests of America, with no other guide than that of the colour produced by the light of the

sun on the sides of those *trees*, &c. which are more directly exposed to its action.

Lastly, with regard to light, I would mention the singularly useful, and hitherto unobserved *effect of moonlight*, in assisting the completion of certain important natural phenomena. The crystallization of water, under the form of those light frosts which so much prevail during the early spring, and which are of sucn important service in assisting the operations of agriculture, by rendering the surface of the earth mellow, and better susceptible of the manure that is necessary to it, are greatly assisted, and in many cases entirely brought about by the intervention of moonlight. It is well known that, under certain circumstances, water will sink to a temperature of 22° before it freezes, or takes the form of crystals. Indeed it will invariably do so in the absence of any mechanical agitation, and in the absence of light. It is an unquestionable fact, but one which has not hitherto been observed generally, or attended to, that during that period of the year to which I have alluded, and indeed at other periods, before the moon rises on a still clear night, when the atmosphere is at a lower temperature than 32, the water remains in a liquid state; but immediately on the moon rising, and diffusing its light around, the water freezes, and

performs the salutary offices required of it, without subjecting us to the severity of a low temperature.

Day-light then may well be called "the light of heaven," since it not only enables us to see all things that come within the range of our optical organs, but actually communicates a great portion of that beauty which it shows to us; since it not only sheds upon the flowers those hues which make the face of our earth a vision of delight, but it assists in giving health to the human frame, and paints the cheek of beauty with those colours, which no art can imitate, and no eye can help admiring.

In our previous examination of light as a chemical agent, I had occasion to speak of *day-light or solar-light*, as distinguished from the light produced by common *combustion*. I allude to the mention I made of certain mixed gases combining chemically, with a violent explosion, when exposed to the action of day-light, but remaining mechanically mixed and unchanged when presented to the influence of that light arising from combustion. This fact proves those two kinds of light to be essentially different in their natures.

As solar light therefore in its chemical effect is totally different from the light arising from combustion, it follows that they are produced by a different cause. This naturally leads us to a con-

sideration of the cause of solar light, and the nature of the sun itself.

There are many circumstances connected with this subject to which I beg to call your very serious attention, before I lay before you the opinion that I have formed on this point.

The first circumstance, and one of the highest interest, is the *natural position of the magnetic needle.* We invariably find that when free to move on its centre, it points north and south, and never alters this position unless acted on by an adventitious cause; I mean by any cause differing from that invisible and imperceptible influence which occasions its natural direction. That the needle assumes this position under the influence of some ever-active power is evident. I shall here recall your attention to our experiments when treating of electro-magnetism. In these experiments it was seen that the moment *a current of electricity* passed in the neighbourhood of, and in a direction parallel with, the needle, it instantly started from its natural position of north and south, and crossed the current, and pointed east and west, in which position it remained sationary so long as the current continued to pass. And that common needles were made *magnetic* by passing electrical currents round them. From these facts it appears that electricity is the cause of magnetism, and that the position assumed by the needle is dependent on the same cause.

When we suspended a globe of copper-wire, and passed a current of electricity round it, it was seen *to revolve* uniformly on its axis: thus proving that electrical currents are capable of producing revolution.

With these facts before us, may we not suppose that electrical currents are constantly passing round this earth, in the direction of east to west, and produce at once the north and south direction of the magnetic needle, and the diurnal revolution of this earth on its axis?

It was also seen, that whenever electrical currents passed through good conductors, and the current was allowed to circulate without being broken or disturbed, that no visible effect was produced, except that of its influence on the needle, &c.; but that, on the contrary, the instant the current was broken or disturbed, light and heat were suddenly produced, and in quantities proportioned to the electrical current. Now the light produced by electricity possesses exactly the same chemical properties as solar light, in every respect. It occasions the combination of chlorine and hydrogen; it influences crystalization; it produces oxidation, &c. &c., in the same manner as these are effected by the direct rays of the sun. With these further facts before us, may we not suppose, that not only the revolution of this earth,

but also those of all the other planets of our system, are in fact produced by similar currents of electrical matter, at certain definite distances from each? That they all meet in one common centre, or point, where consequently they must be broken and intercepted by each other, and where the production of intense light and heat must be the natural result; and finally, that the point at which they do so meet, and at which this light and heat are so produced, is in fact the sun? hence the identity of electrical and solar light.

Many facts, independent of those to which I have alluded above, seem to me to sanction this opinion, for I do not scruple to designate it as such, as far as regards myself; but the above are so striking, that I have thought it worth while to submit them in particular to your attention. I submit them, however, with great diffidence, and merely as hints and conjectures; and the rather, because it is but within a very short time that I have made the matter a subject of my thoughts, and because moreover the subject is one of such overwhelming grandeur and sublimity, that it must be approached by all with an awe-inspiring modesty, much more so by one whose pursuits and habits have not given him those adventitious advantages which others possess for such inquiries.

With respect to the other grand phenomena of

external nature, it is well known that lightning and thunder are effects chiefly resulting from electrical causes. It is not improbable that volcanoes may be occasioned by the decomposition of water, by means of the metallic bases of the earths. These bases may be supposed to exist in their metallic state in the deep recesses of the earth, and to burst into flame immediately on the contact of the water, which reaches them from time to time.

In the syllabus of this lecture I have named agriculture, and the economy of animal life, as part of the subjects I should treat of. A more mature consideration of the matter has convinced me, as I was aware that the necessary experiments in illustration of the foregoing subjects would take up much of our time, that I should better further the objects of the course of study, by confining my attention to a very few of the grand phenomena of nature. In so doing I have probably been enabled to render my examination of them somewhat intelligible and interesting; whereas, if I had included the other branches of the subject that I have alluded to, I should have been compelled to treat of the whole so slightly and unsatisfactorily, that those among my hearers who are at present unacquainted with the matters I might have spoken of, would have gone away with little better than a confused and useless impression of ideas without connexion,

and phrases without an application, and therefore without a meaning.

I have therefore confined my attention to the foregoing phenomena of external nature; and I may venture to assure you, that nothing but the want of time has prevented me from being able to trace the same necessary connection between all the important and striking phenomena of nature, and the sublime science of which I have endeavored to lay before you the elements. I should have no difficulty in making it evident to you, that all these phenomena stand, with respect to chemistry, in the relation of cause and effect. Of course, I would be understood to mean simply what logicians imply by "proximate cause:" the ultimate and actual causes of all things must be referred to a higher origin, and into the minūtiæ of which it is not our present business to inquire; or indeed into which unassisted human reason has no right, or pretensions to inquire at all; and into which it seldom does inquire without mischievous results. With respect to ultimate causes, perhaps the best and only true philosophy is to love, admire, confide in, and be silent. And the silence of humility well becomes us, when we know that the Being who created all beings, and all things, who is in fact the causer of all effects, has left us (the lords of his creation, and the pride of all his works) in no less actual ignorance of his operations,

than the meanest insect that peoples the dust beneath our feet.

I have thus fulfilled, to the best of my abilities, the undertaking I proposed to myself at the outset of these lectures; namely, to lay before you a sketch of the elements of chemical science. And I have endeavoured to illustrate what I have said, by the introduction of a series of experiments, which I hope it may not be thought presumptious if I allude to as being, with a few exceptions, novel and original. I have less difficulty in mentioning this, because it gives me ground for hope, that any deficiencies that may have been observed in the course of my experiments may meet with more indulgence, than they would have been entitled to claim if I had pursued the common and beaten track.

I would beg permission also to refer to the new matter, in the way of theory, as well as of practical discovery, that I have been led to offer to your notice; because it gives me an opportunity of stating publicly and unequivocally (as I now most willingly do), that any good which may result to science in general from these discoveries, as well as any credit or advantage that may accrue to me in after-life from being the agent in these discoveries, is due to my connection with this institution: for I will frankly confess to you that, but for that connection, it is more than probable

I should never have been led to make them. At all events, I am anxious to disclose rather than disguise the fact, that the improvements, &c. to which I refer, have all been made during the time that I have been occupied in these lectures, and and since I engaged to deliver them here. I cannot take leave of you without expressing the sincere gratitude I feel for the indulgence which I have uniformly received in this place, and which I am so conscious of having needed; but which I should scarcely have felt myself justified in expecting, or even in hoping for, except on the ground of this having been my first public introduction in London, and also my first attempt to address a public audience of any description, still less one who is accustomed, like that now before me, of being addressed by persons of the greatest ability and experience in their respective professions.

*** The regular course of Lectures, agreeable to the Syllabus, ended with that on Natural Phenomena; but as many of the members of the Institution wished me to explain the nature and application of the new oxy-hydrogen blow-pipe, which I have constructed, more fully than I had an opportunity of doing in the previous arrangements; I delivered an extra lecture devoted exclusively to the subject, which lecture is printed as the next and last in the present publication.

LECTURE XIII.

BLOW-PIPE.

So important are blow-pipes in many of our most interesting inquiries, that there is scarcely an age without some improvements being attempted and made in their construction, for the purpose of extending their use and application. The object and use of the blow-pipe is to increase the intensity and to facilitate the application of one of the most powerful agents we possess—namely, that of heat; and the different kinds of these like all other instruments, are valued in proportion as they effect the purpose for which they are intended.

The most simple in its construction—namely, *the common blow-pipe*, is an instrument generally well known. With it the flame of a common oil or spirit lamp is urged by the breath to certain points where it may be required, and the heat is increased by mechanically forcing and concentrating the flame on any particular object, at the will of the operator.

Instead of by the breath, which is found disadvantageous in many respects, the flame is sometimes urged by common air, either by attaching the common blow-pipe or a small jet tube to a chest or box, in which a few atmospheres of air have been previously condensed, or connecting it to a small pair of double bellows, contrived for the purpose. The latter is the most desirable method for using the instrument, and is generally adopted in chemical laboratories; but the common blow-pipe, from its smallness and portability, is usually employed out of it. Besides blow-pipes for the purpose of propelling the flame of a lamp by common air, and with the breath, there are others which permit inflammable gaseous substances to be driven through the jet tube and burnt, so as to produce of themselves a jet of flame. *The self-acting spirit blow-pipe* is a powerful one of this kind; but the greatest intensity of heat known, is that produced by burning in the above method, a mixture of oxygen and hydrogen gases, in the proportions to form water; viz: one volume of the former to two of the latter; and the instrument constructed for the purpose is called the *oxy-hydrogen blow-pipe*. In this instrument, as at present constructed, the gases are condensed into a strong iron or copper chest by a condensing syringe, out of which they force themselves by their own elasticity, first through an apparatus contrived to

prevent explosion, and ultimately through a small tube, at the extremity of which they are burnt, and produce of themselves a jet of flame.

Oxygen and hydrogen gases, when mixed in the above proportions, are so dreadfully and powerfully explosive, that the apparatus just alluded to, and in fact all the means hitherto contrived for the purpose, have been found by experience ineffective in preventing the passage of flame from the jet to the reservoir of the gas, and frequently exploding and bursting the instrument. Dr. Clarke, whose name is generally associated with the above instrument, perhaps experimented more with it than any other man: and he found from experience, in the latter part of his life, that it was necessary, in order to secure himself from the danger attending an explosion, to build a partition between himself and his instrument; and even under these circumstances, did not venture to burn it, but in very small quantities. I mention this to convey to you some idea of the danger attending the use of the instrument in question. Every other scientific man has had similar feelings respecting it: consequently it never has been used with any advantage to science nor to the arts, or can be under these circumstances; in fact, a few bold experimentalists only have dared to use it, and those, as may easily be supposed, under the most unfavourable circumstances for practical utility.

By every other method which has increased the intensity of heat, we have always effected corresponding advantages; but although the unequalled power of a mixture of oxygen and hydrogen gases have been known almost ever since their first discovery, yet not a single instance can be pointed out where they have furnished a fact of the least value to science or society. The true reason of this I conceive, in the present age of knowledge and application, to be first the great danger and dread which attends the use of the instrument; and secondly, the little comparative power the few who have experimented with it dare to produce; otherwise I cannot conceive why the intensity of heat of the mixed gases should not be applied to some useful and manufacturing purposes, as well as that which is obtained by other processes.

With these impressions on my mind, and being also desirous of making some discoveries valuable in science which should entitle me to merit your approbation, and seeing that scientific discoveries are generally made by improvements in our instruments; I endeavoured either to improve the present important one by removing the danger attending it, or to construct another which shall render the combustion of the mixed gases safe and unlimited.

Under the stimulus of your patronage, I trust I

have in part succeeded; and if it meets with your approbation, or if I render science or the useful arts the least advantage by the instrument I have constructed, I shall be more than compensated for my exertions.

I shall detail the experiments which I have made in my attempts to accomplish my object, because they will be interesting to many of my audience, so far as they develope many singular facts connected with gaseous bodies and flame, hitherto, as I believe, unknown. I shall detail them in the order that the experiments were made, because you will thus be better enabled to judge of the instrument which is before you; and perceive the correctness or the errors of my ideas respecting those facts; or detect the true cause by which the most interesting were produced, and perhaps apply them with advantage in some of your own investigations.

Wire gauze, which forms the safety apparatus in the condensing oxy-hydrogen blow-pipe, having been proved by the frequent explosion of that instrument to be incapable of preventing the passage of the flame of the mixed gases it became necessary, for better security, to substitute a more impermeable apparatus for the purpose, or to remove every appendage connected with the instrument, which in case of explosion would be likely to do an injury to the operator. The

latter being the most simple object, was, in fact, actually necessary to be accomplished before any experiments to discover the former could be made. In my first experiment I therefore substituted a silk bag, or, what proved to be better, a common bladder, as a gasometer to contain the mixed gases, instead of the copper chest into which they had been usually condensed.

As a substitute for the elastic force which is obtained by condensation, it became necessary for me to make a certain pressure on this bladder, and that too without adding any thing for the purpose which would do mischief in case an explosion of the gas should happen. This I accomplished by placing the bladder containing the mixed gases on a table or stand constructed for the purpose, and placing a piece of pasteboard over the top of it, to which four small strings were fastened and made to pass through holes in the stand, and to unite below the table in question; to these strings I attached a certain weight, so as to draw down the pasteboard on the bladder, and give it any pressure which I required. This pasteboard was so very slight, that no mischief could happen from it in case of an explosion; and the weights being placed under the stand, were completely out of the reach of such accident. It is evident that, provided I wished in my future experiments to obtain greater pressure than that now

applied, I could do so by adding weight to the strings, without any increase of danger.

Having now removed all danger in case of explosion, and also provided against accident; I contemplated in the next place the most important point, viz. to provide an apparatus which should allow the mixed gases to be burnt at a jet, without a possibility of the flame communicating to the reservoir of gas, wherever it might be situated in the final construction of the instrument.

In my first attempt to obtain a flame from oxy-hydrogen gas, and at the same time an apparatus to prevent its passage to and exploding the bladder, I used a large copper cylinder, perforated lengthways with a very small aperture. I applied this copper tube with a view of preventing explosion, because I was informed from high authority, that from the smallness of the aperture, and the thickness of the copper, this tube would not allow flame to pass, and might be considered as perfectly safe in virtue of its cooling or conducting power. In using this tube, it produced a flame just perceptible, with which I made a few experiments: but had not however proceeded far when the gas in the bladder exploded. I did not think it possible that this explosion could happen through the tube in question, but conceived it probable that it communicated through the side of the bladder, which might probably have a small hole in it, or that the

stop-cock to which this copper tube was connected might leak; in fact, I believed that an escape of gas from some point or other had taken place, which ignited accidentally, and exploded my apparatus.

I therefore submitted this copper tube to another bladder in the same way, taking care that there was no escape of gas from any part of the apparatus. I now again commenced operations, but had not made more than two or three experiments when it exploded as before. I was now convinced, from more exact observation, that it happened through the tube in question. I should observe here, that this cylinder of copper was one inch thick, three inches long, and the aperture through it the eightieth of an inch in diameter.

Being now convinced that the hole through it, although so very small, was too large to insure the safety; and as there was no prospect of increasing my power, or obtaining any advantage in my express object by reducing it, I did not attempt to do so, but made another cylinder of plaster of Paris instead of copper, and increased the number of apertures to twenty, which were much smaller, presuming that if a smaller aperture would render the copper cylinder safe, that an indefinite number of the same would be equally so in the present. These apertures, &c. were made by casting liquid plaster into a large tube which con-

tained twenty lengths of the smallest steel harpsichord, (not piano-wire,) stretched through it, and which were drawn out when the plaster had hardened. I connected the end of this cylinder by a brass cap to a jet sufficiently large for my purpose, and by this means the whole of the gas which passed through the small apertures was made to issue through this jet; it would therefore, I expected, produce more power and intensity when burnt under these circumstances, perhaps in the ratio of twenty to one. In using this apparatus I certainly obtained a much larger flame than I did by the previous one; but the gases soon inflamed through the whole of the tubes, and exploded my apparatus as before.

Conceiving it probable, that in this contrivance the plaster tubes were too short, I made another, and increased their length to six inches instead of three; this also exploded in the same way.

Supposing it possible that the plaster of Paris tubes failed in consequence of this material being a bad conductor of heat, and therefore that the cooling influence was by this means prevented from effecting the safety, I made a cylinder of lead instead of plaster, and made my apertures through it by fine platina wires, which were drawn out of the mould when the lead had cooled. I applied this as my safety apparatus: but this was

as imperfect as the former, for the gas inflamed through it, and exploded the instrument as in the previous experiments. Lead is a good conductor of heat, and therefore its want of cooling power could not be urged in opposition to its employment in this case.

After trying tubes of all descriptions, many modifications of wire gauze, &c. &c., and various other means without success, I could not help thinking that as the gases inflamed so readily through all these substances, so, contrary to our best authorities, that there must be something peculiar either about the instrument I used, or the manner in which I made my experiments, and this I soon after discovered was the case. About this time I observed a singular fact connected with the common condensing oxy-hydrogen blow-pipe, which I had not particularly noticed before, namely, that when the gases were very powerfully condensed in the instrument, that they would not inflame at the jet. Reflecting for a moment, to ascertain the most probable cause which prevented the gases burning when the instrument was overcharged, I concluded it was occasioned by the mechanical force or velocity with which the gas entered the atmosphere, and therefore that if mechanical force prevented it from burning in this case, that perhaps a great reduction of that force produced the opposite effect in my experiments, and occasioned

the gas to inflame so readily through the tubes, as previously stated. The following fact also now forcibly struck me, namely, that the explosions which so readily happened in these experiments almost always occurred when the weight which was applied below the wooden support or table of the instrument on which the bladder rested came to a certain point. On examination, I found in that situation, from the weights taking a different inclination, that the pressure was nearly taken off from the strings, which, from the nature of its construction, must have been very gradually diminished; therefore I now discovered that which was peculiar about my instrument, and the true reason why the gases inflamed through the above tubes, so contrary to our best authorities.

The above fact is of some importance as connected with our present inquiry, and, in connection with the former, furnished a good hint for further experiment, because it appeared to me more than probable, that as the mixed gases under diminished pressure exploded through very small tubes, and would not ignite under strong pressure when actually passing through the flame of a taper, that the principle might be modified and applied with success in a safety apparatus for the instrument I wished to construct; I therefore instituted a series of experiments to examine the true state of the question. In order that my experiments

should be fairly made for this purpose, and that I might ascertain the real mechanical force required, (if such was the case,) to extinguish the mixed gases, I constructed an instrument for the purpose, which was capable of measuring very correctly the actual force or pressure given to gaseous bodies, from one grain to the square inch, up to one pound or more. By this apparatus I obtained some interesting results, which certainly confirmed my notions in the most satisfactory manner. By various modifications of mechanical force, I could explode the gas through the smallest possible tubes that I could procure, of lead, of copper, of pipe-clay, of plaster of Paris, of glass, &c., through the pores of cane; and lastly, through the pores of Honduras mahogany. I could burn the gas with perfect safety for any length of time at the end of a jet the eighth of an inch in diameter; and I could, by great pressure, extinguish it at pleasure.

The instrument with which I made these experiments is very simple, and one which any person may himself manufacture, see plate 6, fig. 1. It is constructed on the principle of the improved chamber-organ bellows, with this difference, that instead of wood forming the upper surface, it is made of paper pasted across to and from the sides of the upper part of the strings. The weight of the wings always preserved the same pressure, and

were correctly balanced by a lever and counter-acting weight. The surface was one foot square, consequently I could measure with the greatest accuracy the actual pressure given to the gas by certain weights placed thereon. The largest jet I used in burning the mixed gases required nearly a pound to the square inch, and the Honduras mahogany exploded under a pressure of three grains. The paper was made to form the upper surface that it might allow an easy escape for explosions, which of course frequently happened.

I made many experiments of interest by this simple contrivance, unconnected with our immediate object. I found that the different gases required different portions of time to escape through given apertures under the same pressure; that the different gases produced specific notes under certain pressure, from certain modifications of reeds; and it is the same instrument by which I produced the steady flame spoken of in my lecture on combustion, by which I believe I have obtained the true temperature at which the combustible gases will inflame. To give you a history of all the experiments which I have recently made with this contrivance will be out of place here, I must therefore pass on to the immediate subject before us.

Seeing that this principle, by some modification, was capable of being applied as the true safety in the instrument I was constructing, I abandoned

every other idea for the purpose, and reflected on the most probable method by which I could apply it as such. It appeared to me possible that the mechanical force occasioned by an explosion of a portion of the gas itself, might be applied so as to effect its own destruction. I first attempted, on this idea, to explode a portion of gas so as to make a sudden pressure on the gasometer, which I knew from experiment would occasion sufficient force to extinguish it when burning under moderate pressure, at the end of a certain sized tube or tubes. This I found fraught with so many difficulties that it was impossible to apply it without a complication of appendages, which would be objectionable in the use of the instrument. I may here remark, that although the mixed gases may be burnt with perfect safety at the ends of almost any sized tubes, under strong mechanical force, yet that we cannot apply it, in this way, for safety in a portable instrument, because I found that it was impossible to stop the current of gas without exploding that which remains in the gasometer, in any other way than by the method just attempted. After many fruitless attempts it ultimately appeared to me, that if immediately behind the instrument where the mixed gases were burnt I made a small chamber, to arrest or contain a certain portion of the gas, and between this chamber and the gasometer place certain sized tubes or layers of wire gauze, by which I knew,

from previous experiments, that the flame would be extinguished when certain mechanical force was produced, that I should obtain instantly, and suddenly, by an explosion of the gas contained in this chamber, sufficient mechanical force to extinguish the gas at once, and thus obtain perfect safety. By this means I should obtain security at the very moment, when it became necessary that the flame should be extinguished: namely, when the flame had found its way through the jet, and before it could possibly reach to the gasometer, or communicate to the other parts of the apparatus. On experiment it proved to be so, for the instant the pressure was reduced, or from any other cause, the flame passed back through the large tube which formed the jet, the gas exploded in this little chamber, and all was instantly and completely extinguished. I now endeavoured to explode the apparatus under every possible pressure: but I invariably found that in every case the flame was extinguished the instant it had found its way into the chamber in question. I also tried larger jet tubes, in order that I might obtain larger and more powerful flames; but in this case I found that the gas was not extinguished when the flame passed and exploded in the chamber; and on inquiry, I found it to arise in consequence of the jet being so large, that it permitted a portion of the explosion to pass through it, and consequently

reduced the mechanical force exerted within. The remedy for this was at hand: namely, to increase the mechanical force by increasing the size of the chamber. This, as may be expected, succeeded to my wishes; and I found from subsequent experiments, that the size of the chamber, to ensure safety, must in every case be governed by the size of the interior tubes and that of the jet to be used. Under these provisions I have submitted it to the same apparatus, and acted on it in the same manner as that by which I exploded it through wood, but have never been able to get it beyond the safety chamber in question.

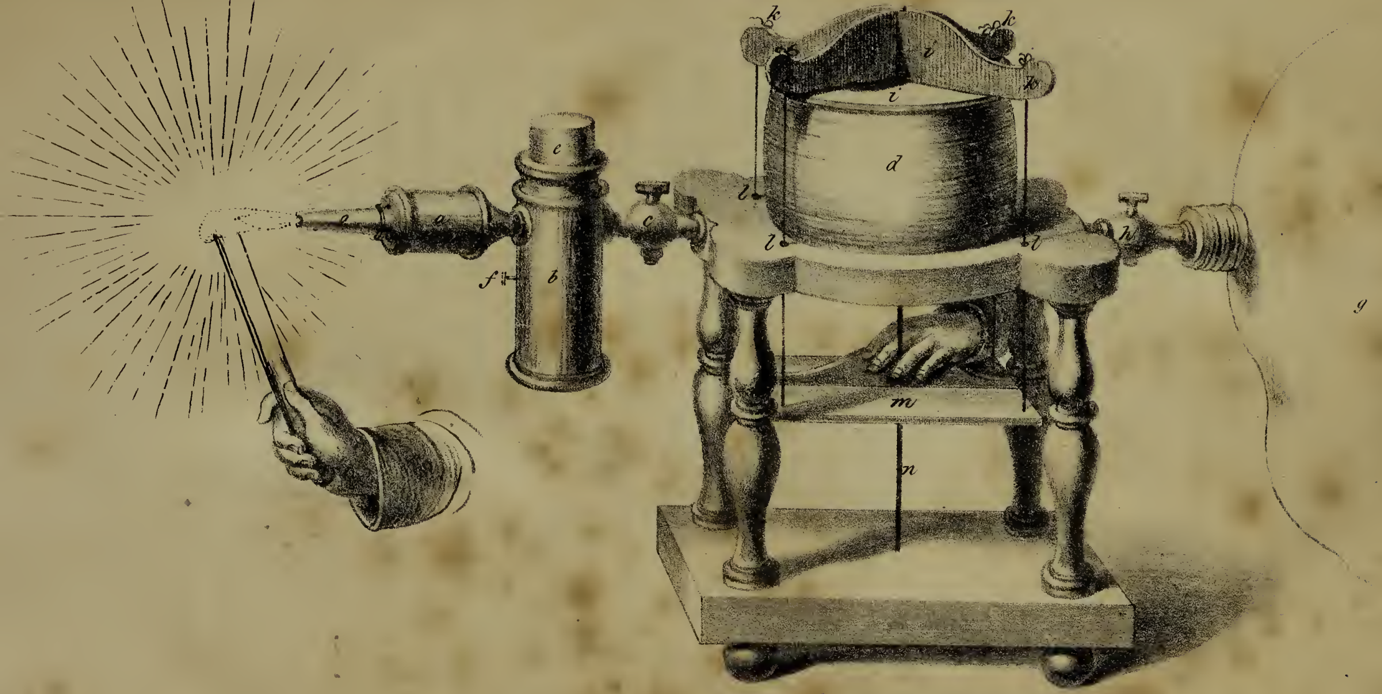
That mechanical force is capable of extinguishing combustible gases may easily be shewn by filling a common bladder with hydrogen; igniting it at a jet in the usual way; and giving the bladder strong pressure, when it will instantly be extinguished.

Whatever the true rationale of the action of mechanical force in extinguishing the explosive gases may be, whether it is from the sudden cooling effect analogous to the blowing out of a candle, or from any other, I will not now stop to inquire; I am satisfied, from experiments carefully conducted, that the effect is certain, which is all that need be attended to at present.

As human judgment is often fallacious, however strong the evidence of our senses may be, and as

one of the principal advantages in the construction of the instrument in question would be that of removing *every apprehension of danger* from the mind of the operator, so that he might coolly attend and examine the changes going on under the instrument, and thus be enabled to render the intensity of heat which it produces unlimited and useful, I have modified the construction of the instrument, as represented in plate 7, fig. 1. (*a*) is the safety apparatus above alluded to, (*b*) a water trough through which the gas must pass from the gasometer (*d*) by the stop cock (*c*), and through a tube which reaches to the bottom of the water; (*e*) is a cork, which in case explosion happens on the surface of the water, is thrown up, and which takes out, to admit water to be poured into the trough when first used; (*f*) a gauge, which is to indicate the necessary height of the column of water in the trough: (*g*) a transferring bladder, which screws and unscrews to and from the stop-cock (*h*), by which the gasometer is charged by an assistant during its action, and the quantity of gas supplied so as to keep up a flame, for any length of time. Between the gasometer and the charging bladder there is a valve placed to prevent a return of the gas; (*ii*) a light pasteboard or wood cap, contrived so as to unite lightness with strength, which in case an explosion of the gasometer happens, is thrown into the air by the force rupturing

Fig. 1.



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the strings, (*kkkk*) which from its extent of surface and great lightness, it is instantly arrested by the action of the atmosphere. To these strings are attached small wires, which pass through holes in the table of the instrument (*lll*), and are again affixed to a moveable press board (*m*) below; this press-board is regulated and kept in a horizontal position by the perpendicular stand (*n*), so that when the necessary weight or pressure is placed on it, it may draw the cap (*i*) horizontally and equally on the gasometer (*d*). The gasometer bladder (*d*), or silk bag, is tied to a bladder-piece, which screws into a long tube, laid into and across the table of the instrument. This bladder-piece, to which the gasometer is tied, permits it to be unscrewed from the table of the instrument at pleasure, and immersed in warm water, to render it soft when occasion requires; or in case an accident happens to it, allows another to be tied on. To one end of the tube, which is let into the table of the instrument, the stop-cock of the charging bladder is attached, and to the other, the stop-cock of the water trough.

When pressure is made on the press-board, the cap (*ii*) is drawn down on the gasometer, and the gas it contains is forced through the stop-cock, water-tube, and ultimately through the safety apparatus and jet at the end of which it is burnt. See a section of the water trough and safety apparatus,

plate 8, fig. 1. I generally use my hand to make the necessary force on the press-board, because I can give it any degree of pressure I please, and increase or diminish it as circumstances may require. The force necessary to keep the flame at the ends of the respective jets is known in the first experiment: for when it is too little, or the hand is taken off from the press-board, the flame returns into the safety chamber and the gas is extinguished. Whenever you wish to suspend the operation, and take off the hand from the press-board for that purpose, the water in the trough acts as a "self-acting valve," in preventing all escape of gas from the instrument; and saves the trouble of turning the stop-cock. When weights are used instead of the hand, the stop-cock of course must be used in every operation.

Jets of various sizes are provided, and screw occasionally into the safety apparatus, at the will of the operator. When large ones are used, a little water will sometimes come over with the gas; to prevent this, I have attached to the under end of the tube which is inserted into the water, a little silk tube or bag, which swims through the water to the surface, thus making a passage for the gas through it, without a possibility of splashing the water. When pressure is taken off the press-board, the weight of water colapses and presses the sides of the silk tube together, and

prevents the escape or waste of gas, without the necessity of turning the stop-cock for the purpose. But feeling confidence in the safety of the instrument, I generally remove the water-trough entirely, and screw the safety apparatus immediately on to the front stop-cock, by the addition of a common connecting piece, when I wish to use a very large jet for any particular purpose.

Quicksilver in the trough produces a jerking motion of the flame, which is very inconvenient and disadvantageous in its effect, as it renders the action and intensity of the instrument less powerful, which will be explained hereafter; but a small column of quicksilver, with a silk tube similar to the above, as advised in the water trough, may be used as a self-acting valve with advantage, for in this case the jerking motion is prevented. Water, however, I think is best; it is always at hand, and presents no serious objection.

Prior to my going into experiments with this instrument, I should observe to you, that I have adapted a flexible tube to it, one end of which is occasionally screwed to the water-trough, and the other to the safety cylinder, by which addition I am enabled to direct the flame into any situation or on any point where it may be required; and such is the facility with which I can handle or direct it, that I can write, or rather burn, any sentence through a steel plate with the greatest

rapidity. This addition is very desirable in many operations, and does not in the least add danger to the instrument.*

The intensity and power of the explosive gases, when burnt by this blow-pipe, is truly astonishing. I have never yet submitted any substance to the action of the instrument, that will not in some way or other give way before it.

Gun flints fuse instantly, and run into transparent glass-like stones. They should be calcined prior to being submitted to the blow-pipe, otherwise the water of crystallization which they contain expands so strongly, that it breaks them in small pieces. All kinds of porcelain fuse readily; but prior to their fusion, assume a beautiful white vitrified opaque appearance. Common china melts into perfect crystal. Tobacco pipes fuse easily, and become vitrified of a yellowish colour. Rock crystal fuses, and gives out considerable light under the operation. The diamond burns and becomes dissipated instantly, producing a fine orange-coloured light. All the precious stones melt, generally, into transparent substances.

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* The instrument, in its present state, and the other appendages, with directions for its use, may be had of Mr. Bancks, Mathematical Instrument Maker, Strand; and as I feel an anxious interest for its success, the safety apparatus belonging to the instrument, under all possible pressures, have been tested by the gasometer before alluded to.

The earths are all strongly affected by its intensity. Magnesia fuses into hard granular particles, which will scratch glass, and throws off brilliant sparks under the instrument. Baryta, strontia, lime, allumina, &c. &c. all exhibit very striking and beautiful phenomena.

The metals all fuse, and burn if the operation is prolonged. A large steel file burns in the most astonishing manner; in fact, it produces a brilliant fire-work; the globles which are first fused, are thrown several feet into the atmosphere, where they burst and scintillate in the most beautiful manner. A clock-spring, watch-spring, and steel and iron in every form, fuses and burns very readily. Gold, silver, copper, &c. all melt and burn easily, assuming various colours, which are very vivid. Platina, which resists very great intensity of heat, fuses and scintillates; and, what is rather singular, more readily than copper or gold: this arises from its being a bad conductor, in consequence of which the heat produced by the blow-pipe is not carried away, but instantly produces fusion, by being retained to the spot where it is directed.

Stones, slates, minerals, &c. of all descriptions melt, or are volatilized, and sublime before the instrument.

Having now stated to you sufficient facts, and shewn sufficient experiments to prove its intensity and power, I shall next call your attention to

those which appear to me to prove the value of the instrument, and the end for which it was constructed,—namely, its capability of being used with practicable advantage to the arts, or to effect some discoveries valuable in science.

First, with regard to the arts: gun-flints, china, tobacco pipes, &c., which I have just stated and exhibited to you as being fused and vitrified, are capable of being coloured in this state, and of the most vivid tints, by mixing and fusing in combination with them some of the metals or other substances, such as chrome, uranium, copper, iron, &c., and when thus united they form very beautiful artificial gems; or, perhaps, I may say real ones, since the same elements are combined by this process which nature combines in her productions.

The light from magnesia is so intense and powerful, that the eye can scarcely look on it during the operation of the instrument; and that from pure lime, is so astonishingly intense and powerful, that it cannot be borne by the eye at all, particularly when under a strong flame of from nine to ten inches in length. The light from lime is not unlike daylight in its appearance; I am confident that one of our largest theatres might be lighted by it with the most splendid effect; in fact, every other artificial light is thrown into shade before it. However fanciful the idea may be, I cannot help thinking that, at some future time, the light pro-

duced in this way from some of the earths, will be used with great advantage in light-houses, &c.

All the metals fuse before it instantly; platina, the most infusible of them all, and which resists the most intense heat of our furnaces, may be fused by the present contrivance in almost any quantity. I have modified the gasometer, pressure, &c. in a larger instrument constructed on this principle, and have kept six ounces of platina in fusion at one time; in fact, by the instrument now before you, a platina bar the quarter of an inch in diameter may be fused. Platina plates may be melted together, and united at their edges; pieces of gold, silver, copper, &c. &c. may all be fused one into the other instead of soldering, as is now commonly used. Soldering is disadvantageous in many respects, not only in the ornamental, but also in the more useful arts; one is, that the simple contact of different metals produce galvanic action, and many of our best retorts, &c. &c. are injured from this cause. Many advantages to the arts I might mention as capable of being effected by this instrument, but which I shall leave to your own discernment: I will therefore pass on to some experiments in support of its application to scientific investigations.

All mineral substances have their compound parts separated by the use of this instrument; in fact, it tears every thing of this kind instantly to

pieces, if I may so express it; so that the elements of which they were composed sublime and volatilize, forming new combinations with each other.

I have observed in all operations with the blow-pipe, that the gaseous and volatile products raise and escape into the atmosphere; and that you thus lose the elements of the substance you are about to examine, and are only enabled to judge of the nature of the mineral, or other body thus acted on, by certain appearances which take place during the immediate time of the operation: this also happens in using the common blow-pipe, when propelling the flame of a lamp; at least, when those substances are operated on which it is capable of subliming. To remedy this obvious inconvenience in mineralogical research, and to enable the operator to preserve all the elements of any solid substance he wishes to examine in chemical analysis, when they are thus separated from their original state by this powerful agent, I have contrived the simple apparatus seen in plate 8, fig. 1, and which I find from experiment to answer the purpose intended. (*a*) is a solid slab of plaster of Paris or of metal, with its upper surface ground perfectly true, so that when a ground glass is placed on it, it may remain air-tight on the edges, similar to that on the table of an air-pump. In the centre of the surface of this plate is a little furnace (*b*), into which one of the jets belonging to the instrument is made to

Plate

Fig: 2nd

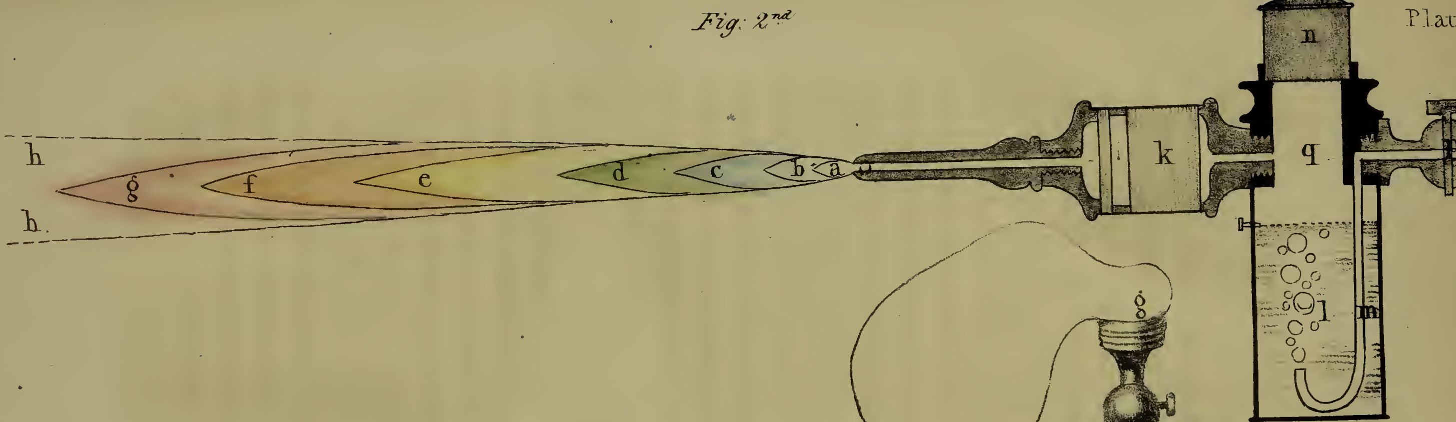
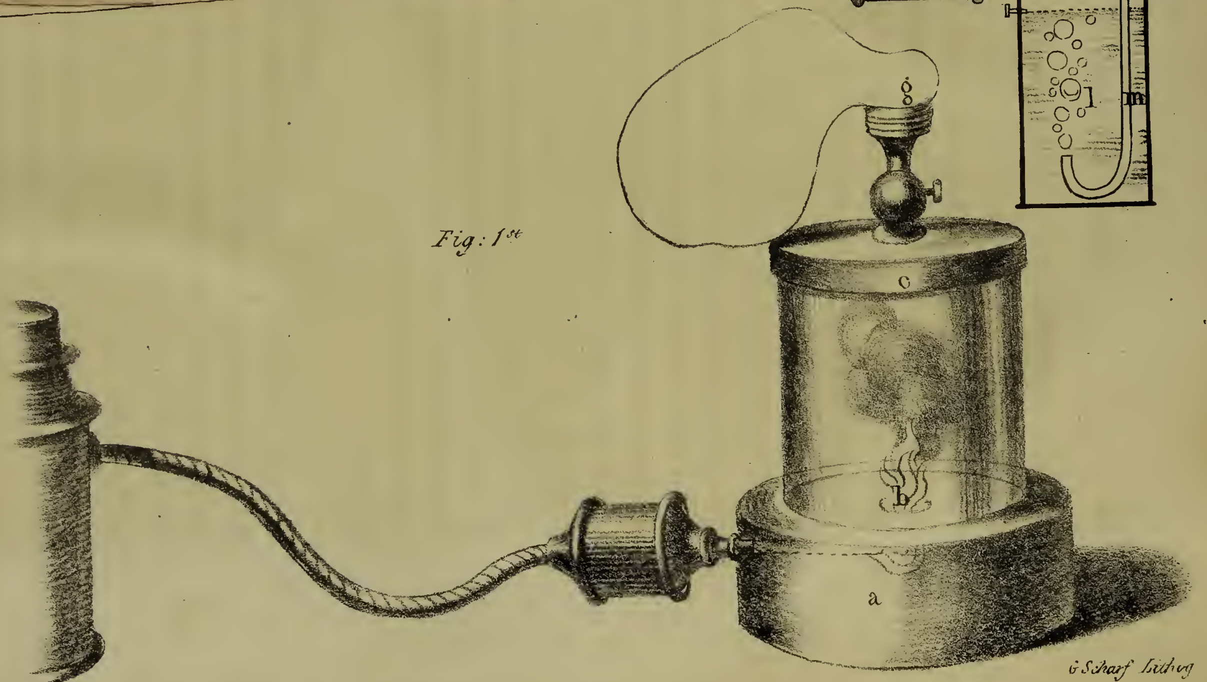


Fig: 1st



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terminate, by perforating from the side through the solid part of the slab. Over the furnace is fitted a ground bell glass, or part of a large tube, with a cap and stop-cock affixed (*c*); and the whole made completely air-tight. To the stop-cock is attached a bladder or silk bag (*g*), in the usual manner.

The method of using this appendage in connection with the blow-pipe is this: the substance to be examined is placed into the little furnace; the jet which perforates the slab is screwed to the safety apparatus of the instrument; and after the pressure has been made on the press-board, either by weight or the hand, the gas is to be inflamed at the jet by a taper, and the glass instantly inverted over the furnace; the intense heat of the blow-pipe will now fall on the mineral, and the whole of the volatile or gaseous parts will raise, and either be condensed on the inside of the glass, or pass into the bladder through the upper stop-cock in the gaseous form; thus the whole of the elements will be retained, and may be examined by the proper tests after the action of the instrument has been discontinued. The glass may be removed by placing the slab under water, either with the safety cylinder and flexible tube attached, or by previously unscrewing it from the tablet, without any possible loss of the contents, and may be decanted into smaller vessels for more accurate examination. Any solid substance, whether a mineral or chemical body,

may be analyzed in the same way, and the most satisfactory results obtained.

Should the water formed by the combustion of the oxygen and hydrogen gases be an objection to the immediate object under analysis, a mixture of chlorine and hydrogen in the proportions to form muriatic acid may be used to produce the flame from the instrument.

In some examinations the water formed by the combustion of the oxygen and hydrogen gases, or the muriatic acid by those of hydrogen and chlorine, entirely prevents a perfect analysis of the substance you wish to examine. It is impossible on this account, for instance, to reduce the alkalies or earths to their metallic state under the naked flame of oxygen and hydrogen gases: for it is a fact well known in chemistry, that as the temperature of many of the metals and other substances is increased, that their appetite or affinity for oxygen also is increased; and that if a metal is not an oxide before, it is sure to become one by giving it increased temperature in the presence of this element. Under the naked flame of the mixed gases, the substance acted on is exposed to the atmosphere, from which it may obtain oxygen in any quantities, and also to that of the water formed by the union of the two gases, from which it may also obtain oxygen by decomposing it: therefore it follows that if an

oxide or a metallic earth is intensely heated by the flame of the mixed gases, it will have its affinity for oxygen so much increased, that it will become farther dosed with it. A piece of pure iron, or its oxide, (if it is capable of uniting with another portion) will take oxygen from the atmosphere, or from the water formed by the combustion; and the blow-pipe, instead of keeping it, or reducing it to the simple metallic state, will produce the per-oxide. This must also be the case with many of the other metals, the earths, alkalies, &c. &c. although there are certain exceptions.

In order to do away with this serious inconvenience, and to prevent the action, not only of the atmosphere, but more particularly that of the water of combustion from interfering with the changes which take place under such intense heat, and to enable the operator at the same time to use the full intensity of the instrument, with the power of adding, agreeable to chemical laws, any substance or substances to assist in decomposition, I have adopted the following simple plan.

Take a small platina tube, closed at one end, and bent like a common retort, so as to permit the open end to be inserted into water or quicksilver in the usual manner, to enable any gaseous matter, which may escape from the tube, to be received over either of these fluids. Into this tube or little retort place the substance you wish to submit to

the intensity of the blow-pipe, and after inserting the open end into quicksilver or water, and inverting a receiver over it in the usual way, direct a large flame, or, what is still better, two or three flames from different jets, immediately on the outside of the tube where the substance to be analyzed is placed; the heat will pass through the platina to the substance within, and thus you give it a temperature nearly equal to the fusing point of platina, and at the same time, completely excluded from the atmosphere and the naked flame of the instrument. It will be obvious, by this plan, that you are enabled to give any substance a greater heat than can be obtained in any other way, and under the most favourable circumstances for accurate analysis: for if any portion of the substance sublimes it is received or condensed over the quicksilver; if it assumes the gaseous form and is permanently so, it will be received in the receiver, and that which is solid will remain fixed in the platina retort. The whole may now be examined by the proper tests, and thus the true elements of a mineral detected, and their proportionate quantities known. Perhaps it is needless here to remark, that any substance or substances may be mixed in the retort to assist in the decomposition, and that the small portion of atmospheric air which is contained in the retort may be displaced, if it is likely to interfere with

the accuracy of the analysis. In this way potassa may be decomposed, and potassium may be instantly formed. Mix together in the retort some pure potassa and iron filings; the iron filings will fuse within the tube on the application of the flame, and at that temperature will take the oxygen from the potassa. A part of the potassium will sublime and be condensed in the neck of the retort, and some will combine with the quicksilver, and be converted into an amalgam. Various other experiments, obvious to the chemist and mineralogist, may be accurately made in the same way.

As platina fuses at the full intensity of the blow-pipe, it will be perceived that we lose a great portion of the power we are capable of producing in consequence, because we cannot carry the heat to the greatest intensity without defeating our own purpose. Willing, however, to apply the full effect and intensity of heat obtained in this way, I have substituted tubes or little retorts of pipe clay and china, which admit of a much stronger heat, and possess at the same time all the advantages of the platina. Under an immense flame I have used magnesia.

I have by these latter methods obtained results apparently the most important and interesting; which at a future time, when I have more accurately examined them, I will lay before you, as, however my object in these lectures is to further the

true interests of science, I have detailed the methods I have adopted, which if you think worthy your attention, you can easily apply in your own investigations, and allow me to say you will find them of interest and value.

I shall state, prior to my closing this lecture, some very singular phenomena connected with flame, which I have from time to time observed in my experiments with the blow-pipe.

In many of my attempts to extinguish flame by mechanical force, I observed its colour change to all the tints of the rainbow, assuming the most beautiful and vivid colours. These colours I found were produced by a certain force or impetus given to the gas; and after making various experiments, I was enabled to produce any colour at pleasure, by giving the instrument a certain degree of pressure. The colours followed the degrees of pressure agreeable to their arrangement in the prismatic spectrum, at which I felt not a little interested. Prior to my observing this analogy, I conceived that certain metals or other substances were held in solution in the gas, which either burnt or not, in their passage through the flame, as the combustion was perfect or imperfect, and thus produced the different colours; but when I had made further experiments, I was convinced that these facts were more interesting than I at first imagined them.

I filled the improved pressure gasometer, which I have contrived for making all accurate experiments of this kind, with carburetted hydrogen gas; and after applying a jet about the sixteenth of an inch in diameter to the stop-cock, I gave the gas a small pressure by placing a weight on the top of it: the gas, on being inflamed, burnt with its usual bright white flame. I now increased my pressure by gradually adding weight on the gasometer, and I observed the flame to change from a bright white to a vivid red. I still continued adding weight, and it assumed a yellowish red; but at one time the yellow was very distinct. Still increasing the pressure, a tint of green appeared; and lastly a most beautiful and permanent blue, which I kept up for some time. I now gradually removed the weights from the gasometer, and observed that the colours passed again inversely through the above changes, until the usual bright white flame appeared as at first.

I could not but be forcibly struck with these phenomena, and more forcibly by the striking analogy which they bore to the order of the prismatic colours, which induced me to make further experiments.

The prismatic colours, when thrown on a thermometer, indicate different calorific powers; the least heating ray is the red, and the greatest the violet; and they follow each other in this effect in the order of their arrangement. Wishing

to ascertain if there was also different calorific powers in the above colours which were produced by flame, I held a coil of steel wire in the different coloured flames, presuming that I should be enabled to judge of the comparative temperatures between them, by observing the degrees of redness assumed by the wire; and, singular as the fact is, I found that they all indicated different temperatures, and exactly analogous to those observed in the prismatic spectrum. When I held the wire in the white ordinary flame, it became bright red; but as the various colours passed to the violet, it gradually increased in temperature; in this last colour it was at a bright white heat. By taking off the pressure, the white heat passed again to the bright red as at first, through the various stages of colour.

In making the experiment afterwards, while I was holding the coil in the blue violet flame, I placed another weight on the gasometer, which produced sufficient mechanical force to *extinguish the flame* entirely; I now expected the wire to become suddenly cold, but to my surprise, instead of cooling, it instantly assumed a brighter appearance, and *fused into globles* in the most beautiful manner imaginable. At this time there was not a vestige of flame visible, and I held it in this situation until the whole was completely fused.

In the prismatic spectrum, *a little beyond* the violet or visible ray, the greatest heat is produced;

so in this case, although I could only produce a bright white heat in the blue flame, yet the instant it disappeared, the wire fused and ran into globles.

Conceiving it possible that these different temperatures were produced by the *mechanical rapidity* of the particles of gas impinging on the wire, and not by any peculiar property of the colour, I instituted a series of experiments to satisfy my mind on this point. We have not time now to go into detail of those experiments; but I may state that, according to my ideas, they were fairly made, and convinced me that the mechanical rapidity of the particles of gas on the heated body did not produce the different changes in its temperature. The different known facts relative to flame, confirm this statement. It is a well known fact, that if a blue flame be mechanically driven out from a lamp by the common blow-pipe, more heat will be produced than when the white only is urged on the object. The cause of this, agreeable to the above view of the subject, is easily explained. Again, if the various points in a jet of flame be examined, they will all indicate different degrees of temperature, which increase in exact ratio as you approach the first formation of flame. Amongst my experiments on this subject, I made the following: —I held at the extremity of a flame, ten inches long, as produced from the mixed gases by the blow-pipe now before you, a bar of platina; it

became red hot in this situation; but I could not increase the temperature by holding it in this point any length of time. I now brought it about an inch nearer to the jet: it increased in brightness up to a certain point, at which it remained stationary; I moved it gradually on by short distances towards the jet, and found the heat as gradually increased; when it came within half an inch of the end of the jet, it fused and ran down in globles. On examining this spot, I observed that the flame was hollow, and that the platina had just reached *the commencement of the dark portion* of the flame when it fused.

I am convinced, from this and various other experiments, that flame is not only hollow, or that it consists of a thin film or coat of ignited matter, as stated in my lecture on combustion; but that this coat is composed of several layers, or coats of flame laying one on the other, or surrounding each other; that the outer coat is a perfect white, the next a red, the next an orange, next a yellow, next a green, then blue, and last a violet; and that *within the violet is an invisible coat*, which in fact is the line or spot where the combustible matter is condensed; where the chemical change between the elements take place, and where alone the heat produced by the combustion is evolved or formed.

The experiment just detailed, in my view of it, proves that the bar of platina was gradually in-

creased in temperature, *without any increase or force of mechanical pressure*, as it passed through these various coats or states of flame, and approached towards that invisible coat where I contend that the gases alone are combined, and where, as I have before stated, that the heat produced by their combustion alone is formed.

In order to make my view of it more intelligible, I have drawn a diagram of a section, of what I believe to be the true state of a jet of flame from the mixed gases, and which of course equally applies to all flames whatever; see plate 8, fig. 2, the part within the first line (*a*), consists of the combustible gases in a state of mixture *before condensation*, (*b*) the line or invisible coat of *actual union*, (*c*) the first effect of heat in producing colour, namely, *the violet* layer, the *indigo*, &c. (*d*) the *green*, (*e*) the *yellow*, (*f*) the *orange*, (*g*) the *red*, (*h*) the full combination of rays or *white*, gradually diminishing in the atmosphere.

I would here ask the question—Is not light a product of heat, formed either perfectly or imperfectly, as the circumstances which influence the liberation of heat are favourable or unfavourable to its production? Is there not a *certain temperature* which is necessary to its perfect formation? Does not light diminish as the temperature exceeds this standard? And is it

not diminished as the temperature falls below it? Reasoning from the results of the above experiments, and the facts relative to these subjects which are generally known, I cannot myself help concluding that it is so; and also, that heat itself is an effect of the peculiar change and condensation of the elements of combustion into new forms, and *definite position* of the atoms with respect to each other. See lecture on crystallization.

These are the hasty opinions which I have formed from the results of my experiments; should you, however, find them not supported by your own enquiries, or by mature consideration of natural facts, I trust that the very recent observation of these phenomena, and the little time I have had to devote to the subject, will be a sufficient apology for any errors that I may have fallen into.

I cannot conclude, however, without stating to you another circumstance connected with this subject, and which perhaps I ought to have named at the time I stated my experiments on the effect of mechanical force in extinguishing the mixed gases; but as I omitted doing so at that time, and as it is somewhat connected with our present inquiry, I will introduce it here.

As light, heat, and electricity, if not modifications of each other, appear to be members of the same family, I was desirous of ascertaining

in what manner they would act on each other, as produced in the above experiments; in fact, I wished to ascertain the different electrical states of the different colours, &c., and instituted some experiments for the purpose. In passing a strong discharge from an electrical battery through a ten-inch flame of oxygen and hydrogen gases, I was not a little surprised to observe that *the flame was suddenly extinguished.* On reflecting a moment on this phenomena, it occurred to me that the true rationale of it was to be accounted for on the principle of mechanical force, and which force was exerted on the flame by the passage of the electrical discharge through the atmosphere: and so it appeared to be, for when I passed it through fine points, the flame conducted the discharge silently, and almost imperceptibly, without in the least disturbing it. I now adopted a tube of water, contrived by your able lecturer on electricity, Mr. Woodward, as part of the circuit; the flame was not in the least affected; I passed the discharge in this way through a stream of the gases uninflamed, and they instantly ignited. I have made many electrical experiments relative to the different degrees of conducting power, &c. of the different colours, and have found them all different in this respect; but I presume, that as they indicate different degrees of heat, so they must necessarily produce different degrees of rarefaction and ex-

pansion of the atmosphere, and that their conducting powers vary in proportion as the degree of expansion approaches towards the formation of a perfect vacuum. I shall not, however, give up this inquiry myself, because I conceive it likely, sooner or later, to throw considerable light on these very abstruse and interesting subjects; and should I be fortunate enough to discover any facts worth communicating, I will hereafter lay them before you.

THE END.

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